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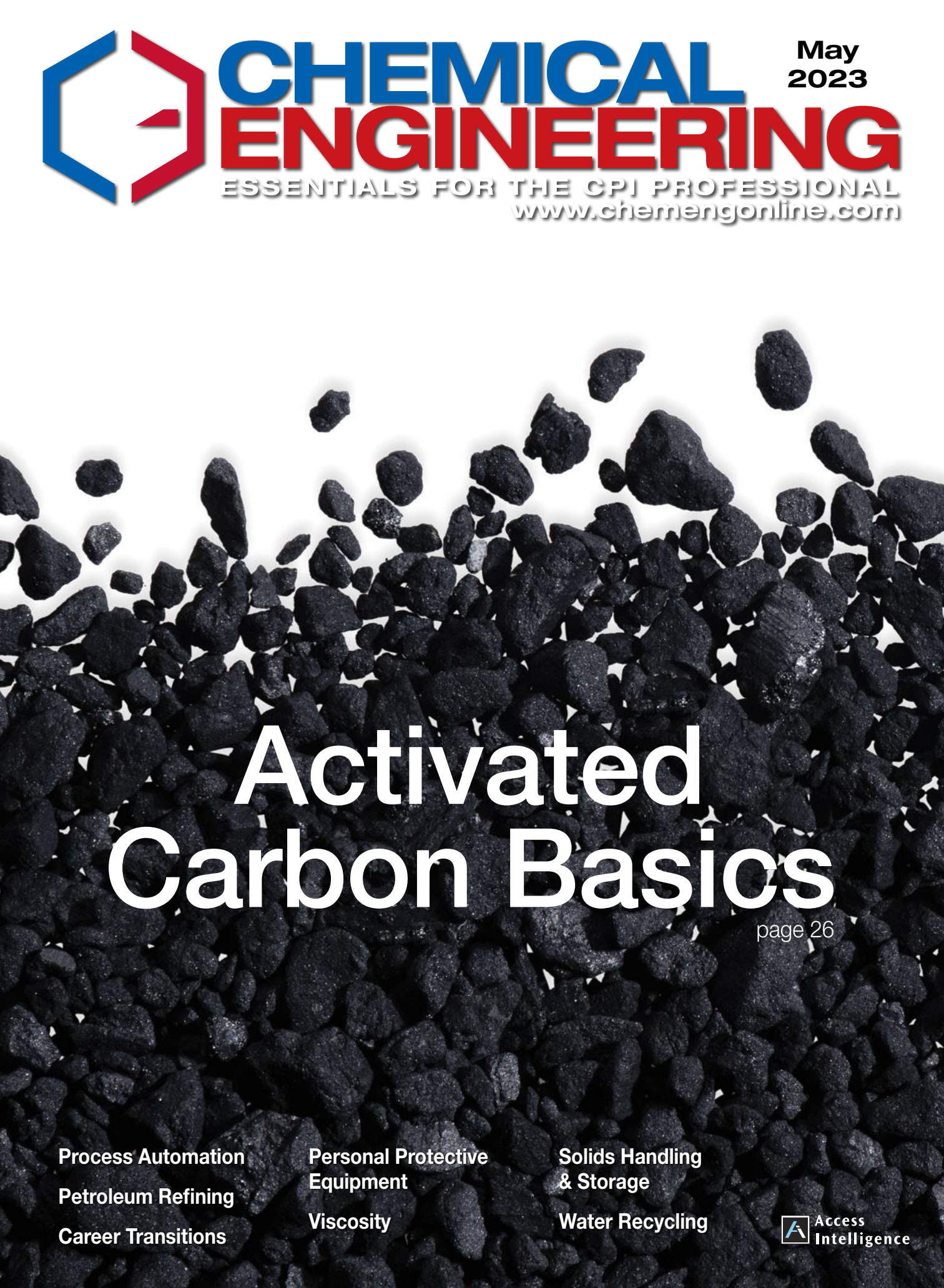

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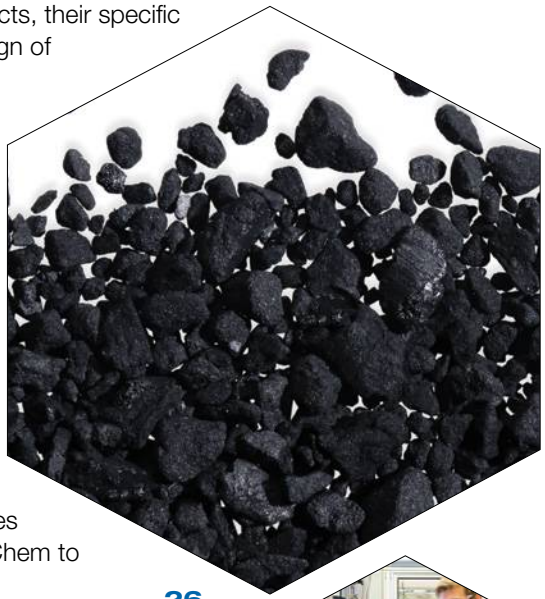

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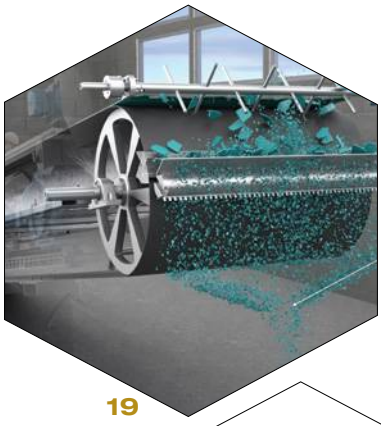

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Editor's Page

Winner of the Chopey scholarship

Chemical Engineering has been a leading source for practical technology information and news for the chemical process industries (CPI) for over 120 years. In addition to being that resource, we strive to bring recognition to, and help advance the chemical engineering profession. With that in mind, *Chemical Engineering* established the annual Chopey Scholarship for Chemical Engineering Excellence to offer assistance to a student who is working toward a degree in chemical engineering. Established in 2007, the award is named after Nicholas P. Chopey, the magazine's former Editor-in-Chief, who devoted over 47 years of his professional career to this magazine.

Aurora Occhino

The 2023 award winner

Congratulations to this year's scholarship winner, Aurora Occhino, a third-year chemical engineering student at the University of Buffalo. Occhino is already looking forward to continuing her studies in graduate school, and plans to get a jump start by including graduate level courses in her senior year, beginning this fall. She currently tutors calculus, chemistry, physics, and MATLAB coding at the university. She enjoys helping and encouraging students in their academic careers.

This summer, Occhino will be participating in an undergraduate summer research program at Texas A&M University. The program involves catalysis research related to energy, sustainability and a circular economy. It includes design of catalytic materials for plastics upcycling; catalytic valorization of abundant chemical precursors such as CO_2, CH_4 and biomass; and reaction kinetics and mechanistic investigation, including spectroscopy. She is excited to begin her career and join the many other engineers who are working to improve the efficiency of how we live today, while also focusing on improving the conditions of the environment. She enjoys exploring the outdoors and looks forward to making her appreciation of the earth part of her career.

About the scholarship

The scholarship is awarded to current third-year students who are enrolled in a full-time undergraduate course of study in chemical engineering at one of the following four-year colleges or universities, which include Chopey's alma mater and those of our editorial staff: the University at Buffalo, University of Kansas, Columbia University, University of Virginia, Rutgers University and the University of Oklahoma. The scholarship is a one-time award. The program utilizes standard Scholarship America recipient selection procedures, including the consideration of past academic performance and future potential, leadership and participation in school and community activities, work experience, and statement of career and educational goals. More information about the award, including how to apply and how to contribute a donation, can be found at www.chemengonline.com/npcscholarship.

In this issue

This month's issue includes our Cover Story on activated carbon, Feature Reports on process control, Newsfronts on petroleum refining and personal protective equipment, a You and Your Job article on choosing career paths and much more. We hope you enjoy reading and find it useful. ■

Dorothy Lozowski, Editorial Director

Technology launched for enhancing propane recovery in GSP

The gas subcooled process (GSP) is a method for low-temperature separation of natural-gas liquids (ethane, propane) from natural gas. Depending on the current market prices of ethane and propane, gas processors extract ethane from the natural gas or reject it and try to recover propane. Newly launched technology from BCCK (Midland, Texas; www.bcck.com) is designed as an add-on for existing natural gas facilities to enhance propane recovery when operating with ethane rejection. Known as G2R-Flex, the patent-pending technology is capable of maintaining a high rejection rate of ethane molecules, while boosting propane recovery.

Developed over the past 18 months, the G2R-Flex is being launched commercially for the first time. In March, BCCK announced the first installation of the G2R-Flex, at a cryogenic gas-processing plant in Ohio that uses the GSP (photo).

"With the addition the G2R-Flex unit, we can observe propane-recovery rates of more than 99% while also maintaining a high rejection rate for ethane," says Jamey Watson, director of process engineering at BCCK, compared to 95% propane recovery with the conventional technology. "The increased propane recovery can have significant financial benefits for gas processing operations," adds Greg Hall, executive vice president at BCCK.

The G2R-Flex setup consists of a set of pumps, a vessel and heat exchangers. To achieve the increased propane recovery, company engineers concentrated on designing the process equipment to carefully control the gas flow within the system.

BCCK

New compressor design for H_2 is leak-proof and improves efficiency

A newly developed hydrogen compressor has a linear motor design and is hermetically sealed to increase the efficiency of H_2 compression while avoiding potential problems associated with H_2, such as leaks and embrittlement. The linear motor-driven reciprocating compressor (LMRC), developed by a team at Southwest Research Institute (SwRI; San Antonio, Tex.; www.swri.org), is designed to compress H_2 for refueling H_2-powered vehicles, such as fuel-cell electric vehicles, but can also be adapted for other gas-compression applications that require hermetic sealing, such as hazardous gas compression or flare-gas recovery.

The small size of H_2 molecules makes leakage a key challenge, and hydrogen can also be absorbed by steel and other metals, leading to a loss of ductility (hydrogen embrittlement).

The new LMRC features an airtight compressor, hermetically sealed using a combination of SwRI-developed solutions. Coatings protect magnets from hydrogen incursion and embrittlement, while improved valve designs minimize leaks, SwRI says. It also utilizes a ceramic piston to minimize heat expansion and lower stress on its seal.

Linear actuation is also a critical aspect of the LMRC. "Typical compressors have a piston and crank mechanism that requires them to make the same motion every time, with every revolution of the motor that is driving it. SwRI's LMRC is linearly actuated, so we can change the linear motion profile to optimize the compression process," explains SwRI principal engineer and project lead investigator Eugene Broerman. The vertical motion of the compressor means that seals and bearings experience less friction, negating the need for traditional lubrication, as required for traditional reciprocating compressors, Broerman says.

Project engineers plan to modify different aspects of LMRC design to further increase efficiency and boost flowrates, as well as apply the LMRC to other compression applications.

Edited by:
Gerald Ondrey

PS RECYCLING

INEOS Styrolution America LLC (Aurora, Ill.; www.ineos-styrolution.com) and Agilyx ASA (Oslo, Norway; www.agilyx.com) are advancing the development of a previously announced 100-ton/d TruStyrenyx chemical-recycling facility in Channahon, Illinois. TruStyrenyx is a partnership between Agilyx and Technip Energies N.V. (Paris, France; www.technipenergies.com) that offers a process for the chemical recycling of polystyrene (PS) back into high-purity styrene monomer. The styrene monomer can be used to make new, food-grade plastic products or packaging.

Under the agreement, Agilyx and Technip Energies will collaborate with INEOS Styrolution and together develop the design and engineering that will serve as the basis for constructing the chemical recycling facility. The group anticipates completion of engineering in 2023, which will form the basis for a financial investment decision.

MAGNETIC COOLING

Together with other investors, temperature-control specialist Lauda DR. R. Wobser GmbH & Co. KG (Lauda-Königshofen, Germany; www.lauda.de) has invested in the startup Magnotherm Solutions (Darmstadt, Germany; www.magnotherm.dom). With this round of financing, concluding at over €5 million, Magnotherm plans to start serial production of its first sustainable refrigerator. Lauda has been following the development of the promising startup since 2019, through its subsidiary new.degree GmbH. The two companies now want to utilize this longstanding relationship and the latest investment of €300,000 to identify strategic reference points for subject areas and projects of shared interest.

Founded out of the Technical University of Darmstadt by the current managing directors, Maximilian Fries and Timur Sirmann, Magnotherm develops sustainable cooling solutions

(Continues on p. 6)

without the use of conventional industrial refrigerants. Instead, it uses a temperature-active, magnetic metal to cool a water mixture. In principle, this technology can be used for any type of cooling.

A pilot plant aimed at demonstrating the magnetocaloric principle for more efficient liquefaction of hydrogen is being planned as part of the HyLICAL project, funded under the E.U. Horizon program. The goal is a prototype with a capacity to produce 5 ton/d of liquid H_2. This will be done by first cooling H_2 to –196°C using liquid N_2, and then to –253°C using Magnotherm's technology. The company estimates that this process can reduce energy consumption by 50% compared to conventional technology.

MXENES

MXenes are compounds similar to graphene and have "extraordinary" electronic properties. These relatively new materials have potential applications in turbines, aerospace and medical implants, but making MAX phase powders (ternary transition metal compounds) at the industrial scale has not been possible before.

MXenes are one of the largest families of 2-D materials. They are a few-atom-thick sheets with the structures of transition-metal carbides and nitrides. Similar to graphene, their distinctive properties, such as high electrical conductivity, make them potential candidates for applications in energy storage and harvesting (batteries and supercapacitors). However, the production of MXenes has been labor-intensive, requiring several steps that include heating a mixture to more than 1,500°C, followed by selective etching with HF or Lewis acidic molten salts.

Now, an alternative process that is faster, simpler and generates less toxic waste has been described by researchers at the University of Chicago (www.uchicago.edu) in a recent (March 24) issue of *Science*. The one-step process involves simply heating mixtures of chemicals and the desired metal at high temperature. For example, the direct synthesis (milligram scale) of Ti_2CCl_2 MXene was performed by the reaction of titanium metal, graphite and $TiCl_4$. The mixture was sealed in a quartz tube and heated to 950°C for around 2 h.

'GREEN' CONCRETE

Carbonaide Oy (Joensuu, Finland; www.carbonaide.com), a spin-out company from VTT Technical Re-

(Continues on p. 8)

Optimizing CIP for membrane filtration plants

Membrane filtration plants are often used in the food and dairy industry to separate or concentrate substances without thermal stress. Until now, cleaning-in-place (CIP) operations for this equipment was energy- and water-intensive, requiring three or four individual cleaning steps with different chemical cleaning agents to be pumped and circulated throughout the equipment for a specified amount of time before rinsing it out with water. Now, water and power consumption can be significantly reduced, thanks to two digital tools — Smart Filtration CIP and Smart Filtration Flush — developed by GEA AG (Düsseldorf, Germany; www.gea.com).

With Smart Filtration Flush, sensors constantly measure the permeate quality of the water during the flushing process, and stop the process as soon as the necessary hygienic level is reached, thereby reducing the amount of water used, as well as the amount of wastewater generated. Depending on the type and size of the plant and the water properties, operators can reduce their freshwater requirements by up to 50%, the company says.

"A typical dairy-whey protein concentration process needs two to four filtration plants connected in a series. This setup can require more than 100,000 L of water, per cleaning cycle," explains Nils Mørk, R&D Engineer for membrane filtration at GEA. "Today, we know from plant tests that we can save well up to 50,000 L of water per cleaning in such large plants and 500 to 700 L per CIP in small productions."

GEA

Bio-inspired synthesis leads to new hydrogen-reaction mechanism

In synthesizing a new molecule that mimics the nickel-iron (NiFe) hydrogenase enzyme, a team of researchers from University of Illinois Urbana-Champaign (www.illinois.edu) may have uncovered a promising alternative to the platinum-based catalysts typically used in the electrolysis of water to produce hydrogen. With the new molecule, the scientists have uncovered a previously unreported mechanism in the hydrogen evolution reaction (HER).

In work published in *Nature Communications*, the team reports that they have, for the first time, demonstrated that both Ni^{I} and Ni^{III} paramagnetic states are accessed during catalytic hydrogen evolution, which is believed to be indicative of the specific chemistry of NiFe hydrogenases.

While other nickel complexes have been investigated for electrocatalytic hydrogen production, their reaction intermediates and activity did not support an efficient reaction. The key to the new catalyst's efficiency is the formation of the paramagnetic intermediate species at the nickel center. The intermediates' unpaired electron and short lifespan mean that the HER proceeds more efficiently than with other nickel-based catalysts. The molecule's unique behavior when compared to other catalysts is due in part to a carbon-hydrogen bond located near that nickel center, which is cleaved and mended during the reaction, helping to stabilize the paramagnetic species. Furthermore, the molecule was outfitted with a specialized ligand based on 3,7-dithia-1(2,6)-pyridina-5(1,3)-benzenacyclooctaphane that could support the paramagnetic states and their seemingly challenging behavior — a direct mirror of the cysteine ligands found in NiFe hydrogenases.

The new catalyst exhibited high turnover frequencies for hydrogen production in the presence of trifluoroacetic acid. The team hopes that this work will spur deeper research into bio-inspired organometallic complexes.

search Center of Finland, has raised €1.8 million in seed funding led by Lakan Betoni and Vantaa Energy. The company will use the funding to integrate its CO_2-curing technology into an automated production line at its precast concrete factory in Hollola, Finland. With its factory-sized pilot unit and fully operational value chain, Carbonaide can mineralize up to 5 ton/d of CO_2 and increase production by 100-fold of its carbon-negative concrete products.

Carbonaide developed a carbonation method that binds CO_2 into precast concrete using an automated system at atmospheric pressure. The technology can halve the CO_2 emissions of traditional Portland cement concrete by reducing the required cement content and mineralizing CO_2 into concrete. When industrial sidestreams, such as industry slags, green liquor dregs and bio-ash, are used in the binding process instead of normal cement, the result is concrete with a negative carbon footprint. In the process, CO_2 is permanently stored and removed from the carbon cycle.

Carbonaide's vision is to open ten operational units in the Nordics by 2026 and bind approximately 500 megatons of carbon dioxide annually by 2050 — corresponding to 10–20% of the concrete market.

ARTIFICIAL LEAF

Scientists have announced a record-breaking achievement in the development of efficient and low-cost artificial leaf-type devices capable of directly converting CO_2, water and sunlight into sustainable fuels. The device was developed by a European consortium coordinated by professor José Ramón Galán-Mascarós from the Institute of Chemical Research of Catalonia (ICIQ-CERCA; Tarragiba, Spain; www.iciq.org), with research institutions from France, Germany, Italy, Spain and Switzerland under the A-LEAF project (www.a-leaf.eu).

The final outcome of this €8-million, artificial-photosynthesis research project — one of the biggest funded by the European Commission — consists of an autonomous device able to convert CO_2 and H_2O to fuels using sunlight. This cell provides a solar-to-fuel efficiency of over 10%, reaching world-record current densities without the use of any critical raw materials.

The team introduced a concept for simultaneously producing H_2 and formate (an H_2-storage element), with the latter used to produce H_2 in the absence of sunlight. This solution allows continuous H_2 production using

(Continues on p. 9)

Scaleup for a hydro-organic-metallurgical process

Following a successful proof-of-concept to recycle spent lithium-ion batteries (LIBs) using reagent extracted from fruit peel waste, Nanyang Technological University, Singapore (NTU; www.ntu.edu.sg) has partnered with Se-cure Waste Management Pte. Ltd. (SWM; Singapore; www.se-curewaste.com) to scale up the technology in a pilot plant. The pilot plant, which has been operational since late 2022, has the capacity to process up to 2,000 L of shredded LIBs.

Over the course of this year, the NTU and SWM team will work to optimize processes that maximize the extraction yield of valuable metals. They will also evaluate the plant's technical performance and economic viability with the goal of commercializing the technology.

In 2020, an NTU team successfully extracted over 90 wt.% of the metals found in processed LIB waste in the laboratory using orange peel waste and made new batteries with these recovered metals (*Chem. Eng.*, October 2020, p. 6). The process, which uses fruit peel waste instead of conventional strong chemicals and acids to extract metals from battery waste is called hydro-organic-metallurgy. Since then, the scientists have successfully replicated their laboratory results using other types of fruit peel waste (pineapples, pears and lemons).

On average, SWM processes 18 metric tons (m.t.) of spent LIBs every day. The company first shreds and crushes spent LIBs and then separates out plastics and some metals, such as Cu, Al and Fe. The final product, called black mass, contains the metals to be extracted for reuse (Co, Li, Ni and Mn). This black mass is fed to the pilot plant, where it is dissolved in chemicals derived from fruit peel wastes. These chemicals, for which the scientists have filed a patent, leach out metals at relatively low temperatures. The leached metals are then precipitated as salts that can then be used for making new LIBs.

Converting algae shells into 'tunable' perovskites

A research team, led by scientists at the Center for Molecular Bioengineering (B CUBE) at the Technical University of Dresden (Germany; www.tu-dresden.de), has converted mineral shells of single-celled algae into lead-halide perovskites with tunable physical properties. The new perovskites have unique nano-architectures unachievable by conventional synthetic production. The results were published in the journal *Advanced Science*.

"Unicellular organisms have responded over hundreds of millions of years to a wide range of environmental factors, such as temperature, pH and mechanical stress. As a result, some of them evolved to produce absolutely unique biomaterials that are exclusive to nature," says Igor Zlotnikov, research group leader at B CUBE, who led the study. "Minerals formed by living organisms often exhibit structural and crystallographic characteristics that are far beyond the production capacities offered by current synthetic methods."

The team focused on *L. granifera*, a type of algae that uses calcite to form shells. Their spherical shells have a unique crystal architecture — the crystals are aligned radially. "The current manufacturing methods of perovskites are not able to produce materials like this synthetically. We can, however, try to transform the existing natural structures into functional materials while keeping their original architecture" adds Zlotnikov.

To transform the natural mineral shells of algae into functional perovskites, the team had to substitute chemical elements in calcite. To do that, they adapted a method developed by their collaborators at the AMOLF institute (Amsterdam, the Netherlands; www.amolf.nl). During the transformation, scientists were able to produce different types of crystal architectures by altering the chemical makeup of the material. In that way, they could fine-tune their electro-optical properties. For example, by converting the calcite shells to lead halides with either iodine, bromide or chloride, the team could create functional perovskites that are optimized to emit only red, green or blue light.

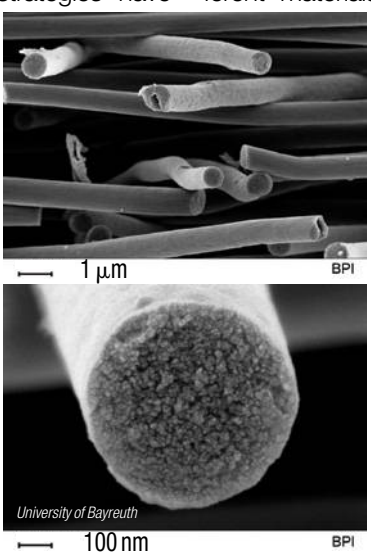
These nonwovens are electrically conductive, but thermally insulating

Researchers at the University of Bayreuth (Germany; www.uni-bayreuth.de) have developed nonwoven materials that exhibit an unusual combination of high electrical conductivity and extremely low thermal conductivity. These composites of carbon and silicon-based ceramic can be manufactured and processed cost-effectively by an electrospinning process, and have potential for applications in energy management, battery-powered electromobility, smart textiles or aerospace.

Normally, high electrical conductivity is associated with high thermal conductivity, and vise versa. However, there is growing interest in multifunctional materials that combine good electrical conductivity with low thermal transport. Although several strategies have been developed in materials such as dense-inorganic materials, conjugated polymers and alloys, achieving extremely low thermal conductivity in combination with high electrical conductivity is still a major challenge for flexible, foldable materials.

As described in a recent issue of *Science Advances*, the new electrospun nonwovens (photos) consist of fibers with a diameter between 500 and 600 nm. Each fiber contains a matrix of carbon in which nano-sized ceramic phases are homogeneously distributed. The particles form tiny "islands" in the "sea" of carbon matrix and have opposite, complementary properties. The carbon matrix enables the electron transport in the fibers and thus high electrical conductivity, while the nano-sized silicon-based ceramic prevent thermal energy from spreading. This is because the interface between the nano-sized ceramic and the carbon matrix is very large, while the pores of the nonwoven are very small. As a result, there is a strong scattering of phonons — the smallest physical units of vibrations triggered by thermal energy — and thus a continuous, directed-heat flow does not occur.

In comparison with more than 3,900 different materials (ceramics, carbons, natural materials, synthetic polymers, metals, glasses and various composite materials), the electron transport and thermal insulation was more coupled with the new nonwovens.



Bayreuth scientists from different research centers collaborated in the development of the new material and the necessary preliminary studies: the Bavarian Polymer Institute (BPI), the Bayreuth Center for Colloids and Interfaces (BZKG), the Bavarian Geoinstitute (BGI) and the Bavarian Center for Battery Technology (BayBatt).

Combining photo- and mechanochemistry for 'greener' synthesis

Solvents are commonly used for performing photochemical reactions. Many of these solvents are toxic, and require additional downstream processing to purify the product and treat waste. Now, by combining light with mechanical energy in ball mills, researchers at Ruhr University Bochum (Germany; www.ruhr-uni-bochum.de) have succeeded in virtually eliminating the need for solvent, while significantly reducing the energy needed to perform a number of reactions. The study, performed by the research team of professor Lars Borchardt, Chair of Inorganic Chemistry, was reported in a recent issue of *Angewandte Chemie International Edition*.

The researchers in Bochum used ball mills as reactors. Here, the starting materials are placed in vessels together with milling balls and shaken at high frequencies. This creates high-energy impacts that provide the mechanical energy for the reaction and thoroughly mix the substances. In a photoreactor that was specially adapted to a ball mill, the researchers were able to synthesize triphenylene via two routes — the Mallory reaction and by cyclodehydrochlorination (CDHC), resulting in yields of 81 and 92%, respectively. The reaction was successfully scaled up to the gram scale. Also, the regioselective assembly of nanographenes by mechanochemistry was demonstrated.

"This new process enabled us to carry out specific reactions and synthesize chemical substances in a much more sustainable way," says Borchardt. "We reduced reaction times by up to 56%, while using 98% less solvent than in equivalent syntheses done with conventional methods. Last but not least, the new photoreactor consumes almost 80% less energy than conventional equipment." ■

an artificial-leaf device for the first time. This approach was validated in a compact electrochemical flow cell, with electrodes based on Cu–S and Ni–Fe–Zn oxide (for proton and CO_2 reduction and oxygen evolution reactions, respectively) supported on gas-diffusion electrodes, integrated with a low-cost Si-based photovoltaic module.

BIO-INSPIRED TEG

Researchers, led by professor Young Min Song from Gwangju Institute of Science and Technology (GIST; South Korea; www.gist.ac.kr), reported a new flexible, lightweight and biodegradable thermoelectric generator (TEG) that gets its inspiration from zebra skin. The design uses a pattern resembling black-and-white zebra stripes to create a high in-plane temperature gradient for generating electricity. The breakthrough was published in a recent issue of *Science Advances*.

The researchers used poly(L-lactide-co-ε-caprolactone) (PLCL), a white, flexible and biodegradable material, for manufacturing the TEG. PLCL reflects sunlight and emits infrared (IR) radiation, which allowed the area below it to be cool. On top of this material, the researchers applied black poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) or (PEDOT:PSS), which appears black to the eye, bringing out the stripes resembling that on the zebra skin against PLCL. The PEDOT:PSS appears black because it absorbs the impinging sunlight while reflecting the IR radiation emitted by the PLCL. This, in turn, increases the temperature of the area below the black stripes, creating a temperature gradient that can then converted into electricity. ❐

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Plant Watch

Evonik plans to double global PEBA production capacity

April 14, 2023 — Evonik Industries AG (Essen, Germany; www.evonik.com) is doubling its global capacity for polyether block amide (PEBA) with a twofold approach, including a major expansion of its production plant in Shanghai and an optimization project at its production facility in Marl, Germany. Construction at the Shanghai site starts in Fall 2023.

Clariant opens new catalyst plant in China

April 13, 2023 — Clariant AG (Muttenz, Switzerland; www.clariant.com) announced the opening of its new Catofin catalyst-production site in Jiaxing, Zhejiang Province, China, representing an investment of CHF 80 million (around $90 million). Catofin is a catalyst for propane dehydrogenation, which is used in the production of olefins, such as propylene.

Merck invests $300 million to expand specialty gases plant in Pennsylvania

April 13, 2023 — EMD Electronics, the electronics business of Merck KGaA (Darmstadt, Germany; www.merckgroup.com) in the U.S. and Canada, announced a roughly $300-million investment to expand its specialty gases facility located in Hometown, Pa. According to Merck, this expansion will make the site the world's largest integrated specialty-gases manufacturing facility.

Air Products to build new nitrogen plants and extend pipeline network in Malaysia

April 10, 2023 — Air Products (Lehigh Valley, Pa.; www.airproducts.com) will build, own, and operate two nitrogen plants in Penang, Malaysia at the Bayan Lepas Free Industrial Zone and Batu Kawan Industrial Park. The company will also further extend its pipeline network in the region.

Resonac to raise production capacity for adhesive films

April 5, 2023 — Resonac Corp. (Tokyo; formerly Showa Denko; www.resonac.com) is increasing its capacity to produce adhesive films with the functions for both dicing tape and die-bonding films used in semiconductor packaging process. With this expansion, production capacity will be raised by around 60% beginning in 2026.

Ascend Elements opens North America's largest facility for LIB recycling

April 5, 2023 — Ascend Elements (Westborough, Mass.; www.ascendelements.com) opened its first commercial-scale lithium-ion battery (LIB) recycling facility. Located in Covington, Ga., the $50-million facility is North America's largest facility for recycling electric-vehicle batteries, with a capacity to process 30,000 metric tons per year (m.t./yr) of used LIBs and manufacturing scrap.

Neste progresses scaleup of waste-plastic processing at Porvoo refinery

April 3, 2023 — Neste Corp. (Espoo, Finland; www.neste.com) has successfully concluded its second series of industrial-scale processing runs with liquefied waste plastic at its renewable-products refinery in Porvoo, Finland. The goal of the processing runs is to further increase the company's understanding of how different types of waste plastics behave during chemical recycling in existing refinery processes. Since Neste's first processing run in 2020, the company has concluded a total of six successful runs, processing close to 3,000 m.t. of liquefied waste plastic in total.

Kraton announces SBS copolymer capacity expansion in Ohio

March 31, 2023 — Kraton Corp. (Houston; www.kraton.com) announced a significant expansion of its styrene-butadiene-styrene (SBS) block copolymers supply capability at its Belpre, Ohio facility. The production capacity is expected to be increased by approximately 24,000 m.t./yr by 2025.

Yara Clean Ammonia and Enbridge to construct blue ammonia plant in Texas

March 31, 2023 — Yara Clean Ammonia (Oslo, Norway; www.yaracleanammonia.com) and Enbridge Inc. (Houston; www.enbridge.com) are jointly developing a world-scale, low-carbon ammonia-production facility as equal partners. The proposed facility, which includes autothermal reforming with carbon capture, will be located at the Enbridge Ingleside Energy Center (EIEC) near Corpus Christi, Tex. Once operational, the plant will have a capacity of 1.2–1.4 million m.t./yr. Total project investment is expected in the range of $2.6 to 2.9 billion, with production startup in 2027 or 2028.

SK Geo Centric to build new ethylene acrylic acid plant in China

March 24, 2023 — SK Geo Centric (SKGC; Seoul, South Korea; eng.skgeocentric.com) signed an agreement with Zhejiang Satellite Petrochemical to build an ethylene acrylic acid (EAA) manufacturing plant in Lianyungang, China, expecting it to be completed by 2028 with a targeted production capacity of 50,000 m.t./yr. This will be the fourth EAA plant at the site. The third plant is under construction, with completion expected in 2025. With the completion of the fourth EAA plant, SKGC's global production capacity for EAA will increase to 140,000 m.t./yr.

Mergers & Acquisitions

Gevo and LG Chem to jointly develop bio-based propylene

April 13, 2023 — Gevo, Inc. (Englewood, Colo.; www.gevo.com) and LG Chem Ltd. (Seoul, South Korea; www.lgchem.com) have entered into a joint development agreement to develop bio-based propylene as a feedstock for renewable chemicals using Gevo's ethanol-to-olefins (ETO) technology. Together, the parties will collaborate to accelerate the pilot research, technical scaleup and commercialization of bio-based propylene.

TotalEnergies to sell three resin product lines

April 11, 2023 — TotalEnergies S.A. (Paris, France; www.totalenergies.com) has accepted an offer from Pacific Avenue Capital Partners for the acquisition of three product lines (Wingtack, PolyBD and Dymalink) developed by Cray Valley, its resin production and sales affiliate. The transaction includes four production sites in the U.S., the Cray Valley Italy affiliate and the portfolio of customers.

Kuraray, PTTGC and Sumitomo jointly open plant in Thailand

April 10, 2023 — Kuraray Co. (Tokyo; www.kuraray.com) is partnering with PTT Global Chemical (PTTGC; Bangkok, Thailand; www.pttgcgroup.com) and Sumitomo Corp. (Tokyo; www.sumitomo.com) to open a manufacturing plant located in Thailand's Rayong Province to produce the engineering plastic polyamide 9T (PA9T), as well as hydrogenated styrenic block copolymer (HSBC). The manufacturing plant has a manufacturing capacity of 13,000 m.t./yr for PA9T and 16,000 m.t./yr for HSBC.

Evonik to sell business assets in Lülsdorf and Wesseling

April 10, 2023 — Evonik is selling its site in Lülsdorf, Germany, and the associated cyanuric chloride business in Wesseling, Germany, to International Chemical Investors Group (ICIG, Luxembourg). With this sale, Evonik will completely divest the production of potassium derivatives and cyanuric chloride, which takes place exclusively in Lülsdorf and Wesseling.

Ineos completes acquisition of Mitsui Phenols Singapore

April 5, 2023 — Ineos Ltd. (London; www.ineos.com) acquired the entire asset base of Mitsui Phenols Singapore Ltd. from Mitsui Chemicals, Inc. (Tokyo; www.mitsuichemicals.com) for a total consideration of $330 million. The business produces over 1 million m.t./yr of product, including cumene (410,000 m.t./yr), phenol (310,000 m.t./yr), acetone (185,000 m.t./yr), alpha-methylstyrene (20,000 m.t./yr) and bisphenol A (150,000 m.t./yr).

Lanxess and Advent complete foundation of Envalior JV

April 3, 2023 — A new materials joint venture, Envalior, has been launched following the acquisition by Lanxess AG (Cologne, Germany; www.lanxess.com) and private-equity firm Advent International of the Engineering Materials business of Royal DSM N.V. (Heerlen, the Netherlands; www.dsm.com). Envalior consists of three divisions: Performance Materials, Specialty Materials and Intermediates. ■

Mary Page Bailey

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Petroleum Refining Decarbonization Strategies

As refiners respond to shifting product demand, pressure to decarbonize operations builds. Investments in low-carbon hydrogen technologies, process optimization and integration projects are on the rise

The petroleum-refining sector sits in a unique place: global demand for refined products — especially diesel and aviation fuel — remains strong, and refining operations generated record profits in 2022. The Russian invasion of Ukraine has prompted many countries to look more intensely at energy security, with an emphasis on established technologies to power economies. But at the same time, the petroleum refining industry is under pressure to decarbonize its operations and dramatically lower greenhouse-gas (GHG) emissions.

The tension between short-term profits and long-term sustainability creates challenging decisions for refineries looking to navigate a pathway to the future of low-carbon energy. Low-carbon hydrogen production, digital technologies, shifting feedstocks and process optimization are among the strategies being pursued for lowering the carbon footprint of refining operations (Figure 1).

"Refinery margins are forecast to be pretty healthy at least for the rest of the decade, and [refining companies] have been practicing capital discipline around fossil-fuel infrastructure," says Alan Gelder, senior VP for refining and chemicals at WoodMackenzie (Edinburgh, U.K.; www.woodmac.com). "There's still investment happening, but it's shifted toward decarbonization-related projects." Wood Mackenzie anticipates an acceleration of investment in low-carbon technologies, including carbon capture, utilization and storage (CCUS), hydrogen, next-generation nuclear technologies and advanced battery chemistries. Analysis by the International Energy Agency (Paris; www.iea.org) found that clean energy investment by oil & gas companies has risen by an average of 12% each year since 2020.

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FIGURE 1. Refineries have been practicing capital discipline around fossil-fuel infrastructure, but have been investing in decarbonization-related projects

"We're seeing a big focus on energy efficiency and process optimization in petroleum refineries," Gelder says. "Refiners are working on reducing site emissions, and looking to produce low-carbon fuels (by co-processing bio-based feedstock, for example). There's also been a coalescence around the idea of refinery-petrochemical integration," he says.

Low-carbon H_2 production

In March, the United Nations Intergovernmental Panel on Climate Change (IPCC; Geneva, Switzerland; www.ipcc.ch) finalized its sixth assessment report on climate change. Regarding the threat of climate change, the report states: "There is a rapidly closing window of opportunity to secure a liveable and sustainable future . . . The choices and actions implemented in this decade will have impacts now and for thousands of years."

The report emphasizes the need for "deep and rapid reductions in gross emissions of CO_2" and other GHG emissions, but acknowledges that some hard-to-abate residual GHG emissions (from agriculture, aviation, shipping and industrial processes, for example would remain and "would need to be counterbalanced by deployment of carbon dioxide removal (CDR) methods to achieve net zero GHG emissions." The need for carbon capture and storage (CCS) in industrial operations is clear: "Global modeled mitigation pathways for reaching net-zero CO_2 and GHG emissions include transitioning from fossil fuels without CCS to very low- or zero-carbon energy sources, such as renewables or fossil fuels with CCS," the report says, as well as demand-side measures, such as improving efficiency, minimizing non-CO_2 GHG emissions, and CDR.

Petroleum refineries are both large producers and consumers of hydrogen, placing them in a key role for a future that emphasizes hydrogen as a no-emissions energy source. Low-carbon hydrogen production is one of the key paths to decarbonizing hard-to-abate industries like petroleum refining and others, such as ammonia production, steel manufacturing and long-haul transportation. In the U.S., Europe and elsewhere, investment in low-carbon hydrogen has been spurred by government policy (Figure 2). The European legislative package known as "Fit for 55" aims to reduce greenhouse gas

emissions by at least 55% by 2030. And tax incentives contained in the U.S. Inflation Reduction Act of 2022 (IRA), as well as grant opportunities under the Infrastructure Investment and Jobs Act of 2021 (IIJA), have also encouraged action.

Relative to hydrogen, Wood Mackenzie's Gelder says "governmental policy is key to changing the economic calculus for carbon capture technology [as required for "blue" hydrogen] and electrolyzers [for "green" H_2], but also the local environment, site-specific and cluster-specific geography and economies of scale also make a big difference." Green hydrogen from electrolysis of water, and blue hydrogen from steam-methane reforming (SMR), partial oxidation or autothermal reforming coupled with carbon capture, are technically viable, but the challenge is on the commercial side — everything you could do to improve refining operations requires investment and adds complexity to the refinery, says Gelder. "There have been a lot of pilot-scale projects and smaller-scale processes using these technologies, but they have not been scaled widely.

A recent report from industry analyst firm IDTechEx (Cambridge, U.K.; www.idtechex.com) forecasts the global blue hydrogen market to reach $34 billion by 2033. "CCUS infrastructure has significant government backing and is being developed by companies worldwide to capture and store emissions from various industries by locating infrastructure near industrial clusters. These forces are accelerating blue hydrogen production, which is expected to grow as global decarbonization efforts intensify," the report says.

In January 2023, ExxonMobil Corp. (Irving, Texas; www.exxonmobil.com) granted a front-end engineering and design (FEED) contract to Technip Energies N.V. (Nanterre, France; www.technipenergies.com) for what would be the world's largest low-carbon hydrogen facility at ExxonMobil's integrated refining and petrochemicals complex in Baytown, Texas. The

FIGURE 2. The global blue-hydrogen market is forecast to reach $34 billion by 2033

low-carbon hydrogen, ammonia and carbon capture facility in Baytown is expected to produce 1 billion ft^3/d of low-carbon H_2 at its planned startup in 2027–2028, ExxonMobil says. More than 98% of the associated CO_2 produced by the facility (around 7 million metric tons per year) is expected to be captured and permanently stored, the company says. The CCS network being developed for the project will be made available for use by third-party CO_2 emitters in the area in support of their decarbonization efforts.

ExxonMobil also made agreements with catalyst maker Topsoe A/S (Lyngby, Denmark; www.top-

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FIGURE 3. Artificial intelligence technology is being employed in the development of refinery catalysts

soe.com) to use Topsoe's SynCOR autothermal reforming technology for the planned Baytown facility, and with Honeywell UOP (Des Plaines, Ill.; uop.honeywell.com) to use Honeywell's CO_2 Fractionation and Hydrogen Purification System at the integrated complex.

For its part, Honeywell is also working with Johnson Matthey plc (JM; London, U.K.; www.matthey.com) on low-carbon H_2 technology. In December 2022, the two companies announced they would be working together to offer JM's LCH autothermal reforming technology, coupled with Honeywell's carbon-capture technology to produce blue hydrogen at scale. According to calculations from JM and Honeywell UOP, the combination enables direct process emissions to be less than 0.1 kg CO_2 per kg of H_2 by capturing carbon at rates above 99%. This provides eligibility for production tax credits within the IRA.

Autothermal reforming (ATR) generates hydrogen by combining the endothermic SMR reaction with exothermic partial oxidation. It is potentially attractive because it can be more efficient than SMR and facilitates carbon capture in some ways.

Hydrogen hubs

Low-carbon H_2 production at petroleum refineries is also a component of several "regional clean-hydrogen hubs," many of which are currently under development. Industrial hydrogen hubs are usually public-private partnerships defined as "a network of clean-hydrogen producers, potential clean-hydrogen consumers, and connective infrastructure located in close proximity."

In the U.S., as part of the IIJA, Congress allocated $8 billion for the creation of multiple "H_2Hubs," to support low-carbon H_2 generation. The Department of Energy (DOE; Washington, D.C.; www.energy.gov) is administering the awards, and received 79 concept papers for H_2 hubs as part of the program. DOE encouraged full proposals from a portion of the initial submissions and the awardees (as many as 10) will be announced in fall 2023.

A substantial portion of the applicants to the program involve major petroleum refiners. For example, the HyVelocity Hub (www.hyvelocityhub.us) on the U.S. Gulf Coast includes Chevron and ExxonMobil, along with a host of other academic and industrial partners. Organized by GTI Energy, Center for Houston's Future and the University of Texas at Austin, the HyVelocity Hub will pursue DoE's goal of limiting carbon emissions to less than 2 kg of carbon per 1 kg of H_2 produced, and reducing the cost of clean H_2 production to $1/kg. Another example is the H_2ALO Hub (h2alo.org), a partnership among the states of Arkansas, Louisiana and Oklahoma, along with a host of participants that includes Shell and TotalEnergies.

Meanwhile, in Europe, H_2 hubs involving refineries are moving ahead, and many involve traditional refiners. An example is the Humber Industrial Cluster (HICP; U.K.; www.humberindustrialclusterplan.org). As part of the HICP, Shell and Uniper are developing a low-carbon H_2 hub at Uniper's Killingholme, U.K. site. In March 2023, Uniper and Shell UK Ltd. awarded Shell Catalysts & Technologies a contract to deliver a process design package for the HICP project, using the Shell Blue Hydrogen Process (SBHP). Two other companies are also working on plant design proposals for the project, and the one that is selected will become the Humber H_2ub project's preferred low-carbon H_2 production technology provider.

The proposals involve building a blue-hydrogen production unit at Uniper's Killingholme site, capable of generating 720 MW of low-carbon hydrogen from natural gas. The CO_2 produced (~1.6 million ton/yr) would be captured and stored in a geological formation in the North Sea.

SBHP is an alternative to autothermal reforming and SMR. It uses Shell gas partial oxidation technology and, compared to SMR and ATR, it captures CO_2 at higher pressures and at larger scales, which results in a lower levelized cost of H_2, Shell says.

Artificial intelligence

Another pathway for refineries to reduce GHG emissions is to optimize processes. The variability of feedstock slates and complexity of refining units offers many opportunities to improve process efficiency and consistency. And artificial intelligence (AI) technology has emerged as tool to help achieve that.

An example of how AI is being used in refinery settings comes from Hexxcell Ltd. (London; www.hexxcell.com), which is using AI to do predictive maintenance of heat exchangers in refineries. As a subset of AI, machine learning (ML) approaches have been used previously for predictive maintenance of rotating machinery, for example, but predicting maintenance for heat exchangers that undergo fouling deposition on thermal surfaces is more difficult because of the complex and varying compositions of crude oils and process conditions. Fouling on heat exchange surfaces reduces efficiency and increases pressure drop, requiring more energy input and emitting more CO_2 for the the same barrel of oil processed.

"Since there is no single solution for heat exchanger fouling, refiners take a largely reactive and preventive approach, but it is often unclear which exchangers to clean, and when, and which cleaning method will be most cost-effective," says Hexxcell co-founder and CEO Francesco Coletti. "We have developed a hybrid AI software that combines ML with physics-based models to generate insights about heat-exchanger maintenance and cleaning."

The combination of ML with physics-based models can offer insights on system-specific fouling that would not be possible with either ML or models alone, Coletti says. "The

AI doesn't have enough data associated with the variety of conditions that could be observed in the heat exchanger to predict fouling without application of the models."

Hexxcell launched a software suite known as Studio to allow engineers to build a process digital twin of the heat exchange system. The biggest benefit of using this hybrid AI approach is avoiding production loss, Coletti says. But the technology also can help reduce fuel consumption and associated CO_2 emissions, and can assist in planning maintenance.

The company has tried and tested their models in a various of proof-of-concepts across several industries and their technology is now implemented in the field at a number of sites worldwide. "It's a digitalization technology that delivers energy efficiency," Coletti says.

In another example, AI is being used to make plant-operation decisions. In general parlance, AI is often discussed as a single technology, but a closer look at AI as a scientific field reveals several types of AI, and a wide spectrum of power and complexity in the technology. Abi Mukund, head of product strategy at Imubit (Houston; www.imubit.com), explains: "Most examples of AI in industry are of a type called 'supervised learning,' which use labeled datasets and standard model frameworks for prediction, such as for predictive maintenance."

Moving beyond that, Mukund's company has developed an AI-based software to create closed-loop neural networks using a type of AI known as "reinforcement learning." In reinforcement learning, an AI algorithm learns to make decisions in a dynamic environment in pursuit of maximizing a particular reward, as defined by the domain expert. This is in contrast to supervised learning, where an AI algorithm is trained on datasets that are labeled by subject matter experts.

Imubit's reinforcement learning AI models are trained to "think" like a human in making decisions and taking action in rapidly changing settings. The reinforcement-learning model is trained on a digital version of the plant that is developed using actual plant data from a data historian in a digital version of the plant. The AI learns how to control aspects of the plant that lead to defined objectives, such as energy efficiency, cost optimization or others.

Plant complexity is extensive and multidimensional. The large physical size of plants means varying time dynamics for a process — the time for material to move through a process doesn't always match the decision-making timeframes. In addition, fouling of process equipment and degrading catalyst activity can affect relationships between process control elements, Mukund says. On top of that, there are volatile feed prices and variable end-product prices that can affect decisions about what feeds to use and what products to make. In real-world refinery settings, variable feed slates and mixing different crude oils together makes it im-

FIGURE 4. Re-activated hydroprocessing catalysts can be re-used for treatment of tailgas from the Claus process

possible to characterize the feed in real time on a dynamic basis.

Because of this complexity, engineers tend to break the problem into pieces, so that each engineer sees a different "picture" of the plant, Mukund says. For example, planning economics engineers, operators and process control engineers all see things differently from their own perspectives. "To try to overcome this, refineries have traditionally turned to real-time optimization (RTO) techniques, but these generally lead to a more "first-principles" theoretical version of the plant that doesn't often match reality," says Mukund.

Reinforcement-learning AI can tackle the realities of refinery operation by using real plant data to train neural networks, then having the AI conduct "trial-and-error experiments" in a digital version of the plant. The AI acquires human-like intuition about how to run the plant to maximize a given objective. Engineers have access to a set of "what-if" applications to run hypothetical plant scenarios on the virtual plant to see what the effects are of decisions.

Imubit's technology has been demonstrated for increasing efficiency and decarbonization at petroleum refining operations. "You can make more high-value products with less waste, and improve energy efficiency by 15–20%," says Roger Wilhelmi, Imubit's senior economic engineer.

A widely held concern associated with using AI for plant control is known as the "black box" problem — if humans cannot discern or explain how an AI algorithm arrived at a decision, should that decision be trusted?

Imubit's Mukund says the company took pains to have users be able to elucidate this question. "We are using what is called 'explainable AI,' which is designed to allow informed human users learn what the AI has learned," he says. "If you have at least a few years of experience in the refinery setting, and you know the plant, you will be able to build models for the AI and discern the insights it has generated."

Imubit's AI software has been installed in a handful of refinery sites, include one run by Delek US (Brentwood, Tenn.; www.delekus.com).

Meanwhile, AI is helping to improve refinery catalyst development as well. In late March, Ketjen Corporation (Houston; www.ketjen.com), a wholly owned subsidiary of Albemarle Corporation that was spun off from the company earlier this year to offer a distinct brand to refinery and petrochemical companies, launched its first product from a new catalyst-development platform that is powered by a combination of high-throughput experimentation and AI. The platform, known as Quasar, brings a new approach to catalyst discovery, development and manufacturing and helps to identify relationships between catalyst preparation, metal active phase and performance (Figure 3).

"We start with our existing knowledge of catalyst formulation, and conduct a series of high-throughput experiments and characterization tests, from which we gather data on a large number of parameters affecting catalyst performance," explains Jaap Bergwerff, research director at Ketjen. "Then we feed the results of those experiments to an ML algorithm that is capable of delivering insights on the right combination of parameters for optimized performance."

The process is iterative, and the ML-generated insights can be used to inform further experiments. "There are many parameters associated with catalyst composition, support and active phase and geometry that can be varied, and the different combinations can affect catalyst performance in interesting ways that are not always apparent when using traditional methods of development," says Bergwerf. "Iterating with ML accelerates the iterative process and leads to catalyst improvements more quickly."

The first catalyst developed using the novel approach enabled by Quasar is called KF882, a high-activity nickel-molybdenum (NiMo) hydrotreating catalyst. According to Andrea Battiston, Ketjen business advisor, the catalyst is able to treat more difficult feedstock than existing hydrotreating catalysts, and it leads to increased volume swell. Both advantages lead to increased profits for refineries. In addition, KF882 allows longer cycles than conventional catalysts, allowing better synchronization of turnarounds and less downtime.

KF882 Quasar can be used with other catalysts in Ketjen's STAX catalyst-loading technology to tailor performance to specific refinery operation needs, says Chad Perrott, Ketjen business advisor.

KF882 "can help refiners generate additional revenue today, which can help free up cash for the company's energy transition," Perrott explains, "and the ML approach used for this platform can be used in the future to develop other catalysts designed for resource sustainability and for processing renewable feedstocks."

Catalyst re-use

In another catalyst-related sustainability play, Evonik Industries AG (Essen, Germany; www.evonik.com) recently commercialized technology to enable reuse of a reactivated hydroprocessing catalyst for treating tail gas from a Claus sulfur-removal unit. Evonik's EcoMax TG demonstrated higher performance than conventional tail gas treating catalysts in laboratory testing (Figure 4), and the performance has been validated in plant tests as well.

Brian Visioli, Evonik global director, SRU/TGU & Purification Adsorbents, says the reactivated catalyst offers improves sustainability, because there is less end-of-life catalyst to landfill, as well as lower cost and better performance. The reactivation process removes contaminants like carbon and sulfur via controlled thermal oxidation, Visioli says. There are currently two installations of EcoMax TG at U.S. refineries. ■

Scott Jenkins

How Protective is Your PPE?

As process technologies — and their associated risks to workers — evolve, personal protective equipment must continue to push the boundaries in both functionality and comfort

Personal protective equipment (PPE) — helmets, fire-resistant clothing, gloves, goggles and so on — can feel like a "second skin" to workers that are frequently exposed to hazardous conditions. But how can PPE wearers be sure that these items are actually providing the protection they claim? In this article, a PPE specialist, Amanda Newsom, principal engineer at UL Solutions, LLC (Northbrook, Ill.; www.ul.com), describes some of the certification processes for PPE used in industrial processing and manufacturing, and the ongoing efforts to improve upon industry standards to ensure that workers are receiving the most appropriate levels of protection. Newsom represents UL on a number of technical committees related to UL certifications and standards.

FIGURE 1. Efforts are underway to enhance the industry standards related to chemical-resistant clothing so that workers are effectively protected while also maintaining their dexterity and mobility

Certifying chemical protection

Due to the large variety of chemicals encountered in industrial processing and manufacturing, it has been challenging to develop overarching standards related to chemical protective clothing. "In the U.S., we don't really have a nationally recognized industrial market-certification for chemical protective clothing, so organizations have to depend on self-declared certification from PPE manufacturers, rather than third-party certifications. Products may be tested by third-party organizations, but they are not certified by them," explains Newsom.

When PPE manufacturers self-declare a certain level of performance from their products, it comes from evaluations done at their own laboratories using their own data, so actual levels of compliance may vary from company to company, depending on the test methods and materials used. This lack of standardization, adds Newsom, can lead to PPE end-users actually overspecifying when it comes to chemical protection. "They evaluate the risks that workers might be exposed to in the facility and they specify a product that they know will provide ample protection, but this often leads to a level of over-protection, which can result in other issues for workers, such as heat stress or accidents due to workers wearing overly bulky clothing." To address these issues, there are ongoing industry efforts to balance the risk assessments that are undertaken by PPE users with product-certification efforts for chemical-protective clothing. "We're working on better aligning these concerns so that people can actually get gear that enables them to do their job safely, without inhibiting their comfort or health," she emphasizes.

A simple example of PPE overspecification is in facilities with risks stemming from both liquid and gas hazards. "In some oil-and-gas facilities, the vast majority of the time, sometimes as much as 99%, workers are going to be exposed to liquids, which allows them to wear a much less-robust protective clothing, because they are really only dealing with a splash. But because they still have the much smaller chance of gas exposure or a gas leak, they may end up wearing a completely enclosed ensemble that has a self-contained breathing apparatus (SCBA) tank," explains Newsom. In such instances, the provision of less-stringent PPE, such as wearable gas detectors, could potentially be recommended, but in the absence of standardization, some companies simply default to specifying the maximum level of protection possible.

A more consistent approach between facility risk assessments and certification activities will enable users to make more informed and efficient PPE specifications so that workers can still be reliably protected without unnecessary discomfort (Figure 1).

Newsom is participating in the development committee for such PPE standards through the International

Organization for Standardization (ISO; Geneva, Switzerland; www.iso.org). Currently, the committee is working to revise the standard that covers chemical protective clothing — ISO 16602. Items covered by this standard include totally encapsulating suits, liquid-tight or spray-tight suits, coveralls, jackets, trousers, aprons, smocks, hoods, sleeves shoe and boot covers and so on. The revisions to ISO 16602 will focus on improving test methods and aligning its specifications on an international scale. The team envisions that once these revisions are complete, the updated ISO 16602 standard could potentially be adopted as a nationally recognized standard in the U.S. that could be used for certification of industrial products. "The goal is to be able to have third-party guidance around certifications for products so that users will be confident in the product they should be wearing for a certain risk level," says Newsom.

All-encompassing protection

While the landscape for chemical-protective standards is still evolving, such certification standards for fire-protective products have been well-established through organizations like the National Fire Protection Association (NFPA; Quincy, Mass.; www.nfpa.org). This has led to a rising trend in PPE solutions that are manufactured to provide both chemical resistance and flame resistance in a single product. "The NFPA just implemented a new certification program for combined chemical and flame protection. The standards have always had an optional flame-resistance test that some manufacturers did utilize, but the test methods have been improved with this revision," explains Newsom. The update, she adds, makes the PPE standards more aligned with the flame-resistance certifications used for the oil-and-gas production and electric vehicles.

Another step forward in PPE flame-protection certifications is the use of full flame-engulfment tests using mannequins. Basically, the mannequin is equipped with PPE products and set on fire using propane torches (Figure 2). After the flame engulfment, the level of protection provided by the PPE can be measured by analyzing the amount of body burn during various durations of flame exposure. UL has added such tests to their chemical testing standards as an option, in the event that flame resistance is required in addition to chemical resistance.

Shutterstock

FIGURE 2. Mannequins are often used to test the effectiveness of flame-resistant PPE items

The evolution of PPE testing

To test and certify PPE products against chemicals, the first consideration is the format of material the user will encounter — liquid, vapor or particulate matter. Because of the wide breadth of chemicals in use across industry, UL uses a list of around 20 representative chemicals for PPE testing to cover chemicals with similar properties, such as vapor pressure. "For liquids and vapors, we will typically start with a chemical permeation test in a cell — you simply put a gas or liquid on the surface of the material and you see how much comes through on the backside over different exposure times," notes Newsom. The specifics of the tests depend on many factors, including chemical exposure levels and whether the fluid is pressurized. For particulate matter, rather than testing samples of the PPE material itself, the focus is on airborne exposure, meaning that the full PPE ensemble must be considered. "For evaluation of exposure to particulate matter, we use live subjects who are dressed in the PPE ensemble that is being tested. We put them in a room with fluorescent particulate matter so we can see if any of it penetrates the ensemble," she explains.

Another crucial point of consideration in evaluating PPE effectiveness is at interfaces — the areas of the ensemble that require a seal to prevent hazardous exposure. Such interfaces include the seal around a facemask, and the ends of the sleeves and legs of garments, as well as the waistband of the garment, if it does not cover the full body.

UL's PPE tests also increasingly consider user comfort. A breathability test looks at not only the ability of air to pass through the material, but also the evaporation of sweat through the material, helping to ensure that workers do not overheat. Breathability has now been added as an option to several PPE standards, whereas it was previously unconsidered in many PPE evaluations.

Another area where PPE standards and testing are continually evolving is in the provision of wearable devices that include electronic components, such as "smart" safety glasses with augmented-reality capabilities and wearable location-tracking devices. "UL issued a standard recently related to virtual- and augmented-reality devices, and we have been getting more requests to look at these devices from an occupational standpoint," says Newsom. However, she says, UL's current safety standards for industrial eyewear cannot be applied to virtual or augmented-reality glasses, but work is underway to develop new standards or revise current standards so that they can better apply to these types of devices. Furthermore, over the past year, UL's fire-service standards have been updated to add hazardous-location testing requirements for electronic devices used in PPE. Newsom expects that similar electrical-safety and hazardous-location requirements will be added to chemicals-related standards with subsequent revisions. ■

Mary Page Bailey

Solids Handling and Storage

Stainless-steel lump breakers for sanitary processing

Nibbler GNB lump breakers (photo) feature a hygienic design as standard for safe installation in food, petfood, bakery, nutrition, pharmaceutical and other sanitary processing facilities. Complying with FDA requirements and certified as hygienic by European Hygienic Engineering and Design Group (EHEDG), the Nibbler deagglomerators feature 316L stainless-steel construction for product-contact parts, continuously welded seams throughout, food-grade drive lubricant, and internals that are polished to a highly smooth Ra ≤ 0.8 µm. The potential for contamination is reduced by design, while cleaning and changeovers move fast and easily. The Nibbler GNB accepts material from a bulk bag unloader, sack tipping station or conveyor and automatically cuts the material down to as small as 1 mm in size without generating fine particles or adding heat history. — *Gericke USA, Inc., Somerset, N.J.*
www.gerickegroup.com

These bag fillers are accurate, and have low maintenance

This company's bulk-bag fillers are designed to fill any size bulk bag with high accuracy, while offering years of trouble-free maintenance. The Model BBF loader (photo) features an inflatable fill head that offers a dust-free seal when loading; dust port with dust cartridge; and manually adjustable bag supports for varying bag heights, which is especially useful for low ceiling heights. Many options are available. — *Best Process Solutions, Inc., Brunswick, Ohio*
www.bpsvibes.com

High-temperature screw conveyors for hot materials

The high-temperature Spiralfeeder flexible screw conveyors (photo) accept heated powders, pellets and other bulk materials at infeed and transfer them downstream. Often set at the discharge end of fluidized-bed dryers, ovens, rotary kilns and other process-heating machinery, the high-temperature conveying systems feature a carbon-steel or optional stainless-steel outer tube and inner steel screw joined with high-temperature silicone and Teflon seals and gaskets throughout the design. A proprietary approach distances the drive mechanism from the hopper to minimize exposure to high temperatures. Suitable for food and pharmaceutical ingredients, chemicals, aggregates and other materials, the heat-resistant conveyor is recommended when the material temperature at infeed reaches 120°F. The screw conveyors are proven to safely transfer a variety of coarse and fine solid and viscous materials with temperatures up to 400°F. — *Automated Flexible Conveyor, Inc., Clifton, N.J.*
www.afcspiralfeeder.com

Tension fabric buildings feature structural steel frame

Combining rigid-frame engineering with the benefits of tension-fabric membranes, this company offers fabric structures that are fully customizable. This design concept provides a high level of flexibility for a wide array of applications and industries, including commercial and industrial warehousing, cold-storage facilities, equipment and bulk material storage, treatment plants and many more. These fabric buildings utilize a durable rigid frame in place of the hollow-tube, open web-truss "hoop" framing traditionally used for fabric structures. The strength of the structural steel frame provides several engineering advantages, most notably the ability to easily customize buildings to the exact width, length and height required. In addition to long clear spans, the buildings have straight sidewalls that maximize the useable square footage inside the structure. — *Legacy Building Solutions, South Haven, Minn.*
www.legacybuildingsolutions.com

Cooling conveyor boosts powder coatings productivity

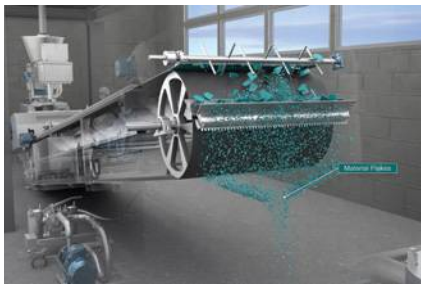
This company has launched a new range of cooling conveyors for powder-coating applications. This addition is key to the availability of

Gericke USA

Best Process Solutions

Automated Flexible Conveyor

Legacy Building Solutions



Baker Perkins

turnkey, fully automated powder-coating process lines from one trusted source. The new stainless-steel belt cooling conveyors (photo) are designed to match the outputs of the company's MPX and HPX series of industrial twin-screw extruders, which can produce up to 2,900 kg/h, across the full range of powder coating and toner formulations. Designed to cool extruded material efficiently and produce flakes that are ideally sized for feeding into the milling stage of the process, the new cooling conveyor integrates seamlessly into the powder coatings production line and helps to maximize end-product quality. All cooling conveyors feature a built-in flaking unit with its own air-vortex cleaning system for dust extraction, which further cuts labor and turnround time while ensuring a high-quality product with minimal contamination risk. — *Baker Perkins, Ltd., Peterborough, U.K.*
www.bakerperkins.com

Automation Products, Inc. – Dynatrol Div.

Field-proven level detection for bulk solids

DJ level detectors (photo) provide high-, mid- or low-point level measurement of bulk solids materials, ranging from low-density flakes and powders to pellets and heavy granular materials. DJ detectors require no adjustments and have no moving parts, gaskets or seals to deteriorate. They provide dependable operation in dusty environments in addition to vessels, storage bins or hoppers equipped with vibrators. Specialized units are available for temperatures exceeding 300°F. All level detectors arrive ready for installation — no field calibration is required. The separate control unit permits easy setup at any convenient location. The DJ is mounted through a ¾-in. half-coupling at the point of desired level detection, eliminating costly flanges, float chamber or fittings. They are approved for Class I, Group C & D; Class II, Groups E, F & G; and Class III services. — *Automation Products, Inc. – Dynatrol Div., Houston*
www.dynatrolusa.com

Flexicon

Bulk-material dumper for single or multiple containers

A new high-volume open-chute dumper (photo) allows discharging of non-dusty, free-flowing or agglomerated bulk materials from multiple drums or boxes simultaneously, as well as from Gaylords, totes or bins individually. The bed of the unit's hydraulically-tipped housing can accommodate containers from 37 to 44 in. in height, having an individual or combined footprint of up to 6 ft by 8 ft. Typical applications for multiple containers include simultaneous dumping of four 55-gal drums, or four boxes, each having a footprint from 36 to 48 in. Pallets weighing up to 5,000 lb are forklift-loaded into the three-sided unit and secured, after which a grate is lowered onto the container(s) to prevent shifting. The lifting assembly is raised to a height of 77 in. and tipped hydraulically, causing material to slide through a smooth, three-sided chute into receiving vessels. Twin hydraulic cylinders pivot the platform-chute assembly to discharge angles of 45 or 60 deg beyond horizontal, including a motion-dampening feature at the termination of container rotation. — *Flexicon Corp., Bethlehem, Pa.*
www.flexicon.com

Munson Machinery Company

This laboratory cone blender discharges fully

A new 1-ft^3 Vee Cone blender (photo) achieves uniform blends of dry bulk solids in 15 to 30 min., with little or no product degradation. Suitable for laboratory testing, pilot plants or low-volume blending of dry powders and granular materials, the unit delivers equal homogeneity at fill volumes from 25 to 100% of rated capacity. Smooth internal surfaces free of baffles, shafts and bearings allow complete discharge through a 6-in. hand-wheel-operated butterfly valve, eliminating material waste. Access to internal surfaces through the discharge valve and twin doors at the ends of the inclined cylinders permits thorough sanitizing in minutes, preventing cross contamination. Driven by a 1-hp wash-down motor, the Vee Cone chamber rotates at up to 30 rpm, imparting a tumbling action that is more gentle and consumes less energy than ribbon blenders and other agitated machines in which blades, paddles or plows are forced through stationary material, the company says. — *Munson Machinery Company, Inc., Utica, N.Y.*
www.munsonmachinery.com ■

Gerald Ondrey

New Products

Emerson

Kaeser Kompressoren

Belimed Life Science

Metso Outotec

Flushing ring reduces maintenance of DP measurements

The Rosemount 319 Flushing Ring with valve-integrated design (photo), ensures accurate differential pressure (DP) measurement and lower maintenance. Available in traditional and compact options, the new 319 Flushing Rings provide a process-to-seal connection and allow for faster diaphragm-seal maintenance without disconnecting them from process flanges. The traditional design utilizes a flow-through cleaning action and can be sized to fit almost any application. Configurations are offered with a choice of ball valves, needle valves or gate valves, and in multiple materials, flange types, sizes and ratings. The compact design removes residual build-up quickly, cleaning five times faster over 30% more surface area and 50% fewer leak points than other flushing rings. — *Emerson, Shakopee, Minn.*
www.emerson.com

A smart oil-water separator for compressors

With the intelligent Aquamat i.CF separator (photo), this company has redefined condensate treatment. Available for delivery volumes up to 90 m^3/min, this new oil-water separator now comes equipped, for the first time, with the Aquamat Control internal controller, which undertakes active management of the process, while simplifying maintenance planning and making service work safe and environmentally friendly, the company says. — *Kaeser Kompressoren SE, Coburg, Germany*
www.kaeser.com

New line of automated washing systems

At Interphex last month, this company unveiled its 2023 line of automated disinfecting wash systems (photo) for North America. Developed for pharmaceutical, biopharmaceutical, nutrition and other manufacturers, the wash systems automatically clean the products and equipment used in the sanitary manufacturing process to a high level of hygiene that complies with FDA, GMP and GAMP 5 guidelines and meets the highest level of data integrity. The washing systems are custom-engineered for each facility or laboratory to decontaminate nearly any type of equipment or component, from delicate laboratory glassware to 55-gal drums, intermediate bulk containers and a variety of production machinery. The product line encompasses 11 models, each available in a range of sizes, capacities and configurations to suit the specific regulatory, throughput, energy-efficiency and other requirements of each installation. — *Belimed Life Science, Inc., North Charleston, N.C.*
www.belimed-lifescience.com

A new range of cone crushers

As a result of continuing cone-crusher technology development, this company has introduced a new HP200e cone crusher (photo) to the aggregates markets, providing more performance and uptime in a more sustainable way, enabled by kinematics and new chamber designs. The new liners are fitted into the crushers without backing material, making maintenance breaks shorter and liner replacement faster, safer and less hazardous for the environment. According to the company, benefits include: enhanced performance, 10% more head motion, 20% more power and 20% more force. Other features include new, more-efficient chambers, an anti-spin brake for higher uptime, serviceability improvements and a feed-cone lifting tool. — *Metso Outotec Corp., Helsinki, Finland*
www.mogroup.com

Green H_2O_2 generation enables safe and chemical-free AOP

The HPGen (photo, p. 23) uses only air, electricity and water as inputs to produce 99.999% pure hydrogen peroxide directly on site. This is done through the company's patented on-site peroxide-generation technology. The output H_2O_2, tradenamed Peroxide UltraPure, can be used in conjunction with an ultraviolet (UV) reactor in an advanced oxidation process (AOP), to remove all trace organic compounds from water. AOP solutions typically require transport, handling, storage and management of

toxic chemicals on site. The HPGen, on the other hand, provides a solution that eliminates chemical input. Output and in-line concentration are readily measurable and controllable. HPGen works automatically and with no need for user intervention — it is remotely monitored, making it essentially plug-and-play. — *HPNow, Copenhagen, Denmark*
www.hpnow.eu

Magnet separator for poorly flowing powders

The recently developed 10,000-Gauss, rotating cleanflow magnet (photo) filters magnetic and paramagnetic particles out of poorly flowing, greasy powders in the food, pharma and chemical industries. The magnet rotor is composed of seven strong magnet bars, equipped with neodymium-iron-boron magnets, each with a diameter of 32 mm. This is 40% thicker than regular magnetic bars and also that used by the magnet manufacturer. The magnetic separator is suitable for free-fall lines and captures both iron and AISI 304 and AISI 316 particles as small as 30 µm from cocoa or milk powder, for example. The separator is available in three sizes, of which the largest model is suitable for product flows of up to 45 m^3/h. — *Goudsmit Magnetics B.V., Waalre, the Netherlands*
www.goudsmitmagnets.com

A smart interface for this vacuum pump series

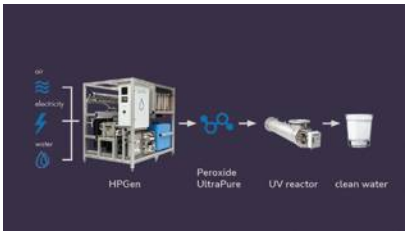
The HiScroll series (photo) consists of three dry and hermetically sealed scroll pumps with a nominal pumping speed of 6–20 m^3/h. These vacuum pumps are characterized not only by their high performance when evacuating against atmosphere, but also by their very high energy efficiency that reduces their carbon footprint. The company is now introducing its intelligent new accessory interface AccessLink, which permits the use of a wide range of optional accessories. Its presence is automatically detected by the HiScroll's electronics. Before this, accessories had to be configured by hand. A uniform accessory interface of this kind enhances convenience and safety during operation. A new gas-ballast valve detects the specific process requirements automatically. The valve is controlled by the vacuum pump, either according to a specific time interval or depending on the inlet pressure, in conjunction with an additional accessory, the HiScroll integrated sensor RPT 010. The automatic gas-ballast valve can also be switched manually by a higher-level controller connected to the HiScroll or by the this company's OmniControl. — *Pfeiffer Vacuum GmbH, Asslar, Germany*
www.pfeiffer-vacuum.com

PID sensors for measurement of VOCs and particulate matter

Photoionization detection (PID) is a recommended technology for detecting volatile organic compounds (VOCs) in many applications, such as environmental monitoring, industrial health and safety, air quality, facility/site monitoring and fugitive emissions. One of the unique features of this company's MiniPIDs (photo) is a patent-protected design with a third electrode that overcomes humidity interference, delivering a stable signal from 0 to 99% relative humidity (RH). The sensitivity of PID sensors is extremely important in many applications, particularly where the sensors are deployed in the measurement of trace VOCs. The NextPM sensor was recently added to the company's portfolio. The NextPM sensors show strong to very strong correlations for both PM1.0 and PM2.5 with reference instruments costing several hundred times the cost of the sensors, the company says. — *ION Science Ltd., Fowlmere, U.K.*
www.ionscience.com

More control optimizes these pellet mills

The new, electronic automatic pellet-mill control system, EAPR (photo), enables this company's machines to operate optimally with low manpower requirements and long service lives. EAPR enables optimum automatic operation of all flat-die pellet mills. It consists of a local control cabinet with touch panel and an intuitive software user interface. Once the process parameters have been specified, the EAPR controls the fully automatic operation, including error and alarm messages, as well as system diagnostics. For more control, an intelligent automatic gap control,



HPNow

Goudsmit Magnetics

Pfeiffer Vacuum

ION Science

Amandus Kahl

IDEC

called Distamat, enables a predefined roller gap to be precisely maintained for optimum production results. The constant gap between the pan grinder roller and the die is essential for pellet quality and stable operation. The system not only increases the pellet quality, but also offers a high degree of automation, which results in less maintenance work during operation. — *Amandus Kahl GmbH & Co. KG, Reinbek, Germany*
www.akahl.com

Improved HMI tablet usability for industrial applications

The HT4P Safety Commander (photo) is an ergonomic device enabling users to securely hold and protect a human-machine interface (HMI) tablet, while providing power, networking and hardwired emergency stop (e-stop) and other operator interface devices. OEMs and automation designers can now provide flexible and safety-rated operator interface options for equipment, robotics, collaborative robots, automated guided vehicles, autonomous mobile robots and other manufacturing system applications. The HT4P can now hold tablets ranging from 10 to 13 in. using adjustable grippers, so users can take advantage of more display area and greater CPU processing speeds. The HT4P Safety Commander accepts more device sizes than ever before, and it adds networking and operator interface options for using modern tablet interfaces with industrial equipment. — *IDEC Corp., Sunnyvale, Calif.*
www.idec.com

WIKA Alexander Wiegand

Electronic pressure switch for hygienic applications

The PSD-4 electronic pressure switch (photo) is a universal solution for industrial automation tasks. Thanks to EHEDG and 3-A certification, the pressure switch is also suitable for industries with high hygienic requirements. Due to an accuracy of less than ±0.5% and minimal long-term drift, it permanently ensures an accurate representation of the process pressure for more than 100 million load cycles. The pressure switch is available with a digital output signal, as well as a switchable and scalable analog output. In addition, it can also be easily monitored via the self-diagnostics. — *WIKA Alexander Wiegand SE & Co. KG, Klingenberg, Germany*
www.wika.de

DuPont

A next-generation of PES in-out ultrafiltration membranes

The first polymeric ultrafiltration (UF) membrane with a completely new geometry since the seven-capillary Multibore debuted over two decades ago, Multibore PRO (photo) combines 19 bores within a single fiber to enable users to realize both performance and sustainability benefits through the increased surface area and reduced installation area for a given flowrate target. With more than double the capillaries, this increased membrane-filtration surface area per module means fewer modules are required in water treatment installations to achieve higher productivity and efficiencies, driving value for operational expenses. UF modules equipped with Multibore PRO membranes can achieve floor footprint savings of up to 15% per rack, while also reducing both capital expenditures due to reduced rack components and assembly costs. — *DuPont, Wilmington, Del.*
www.dupont.com/water

Magid Glove & Safety Manufacturing

Work glove coating for amplified grip in multiple environments

The new VersaTek glove coating (photo) is an intelligent and durable technology that adapts to almost any environment so workers can get their job done without having to sacrifice safety, comfort, grip or dexterity. Engineered stabilizers allow this intelligent coating technology to read the environment and adapt to amplify the worker's grip when working in wet, dry, slick, abrasive or oily conditions. VersaTek is designed for maximum comfort and flexibility so workers can maintain natural hand movements and precision when handling small parts. Plus, this coating delivers over 50% more abrasion resistance than other glove coatings against materials such as sandy nitrile or foam nitrile. — *Magid Glove & Safety Manufacturing Company LLC, Romeoville, Ill.*
www.magidglove.com ■

Gerald Ondrey

Conceptualizing Fluid Viscosity

Department Editor: Scott Jenkins

Viscosity is an important property for understanding the flow behavior of liquids, mixtures, emulsions, slurries and other materials in industrial processes. This one-page reference provides a refresher on conceptualizing viscosity.

Intermolecular forces

Viscosity is a measure of a material's resistance to flow, and is governed by the strength of intermolecular forces among molecules, as well as by the molecular shapes. In liquids, the internal friction results from stretching and breaking the London dispersion forces between adjacent close-lying molecules of the fluid. Liquid flow only occurs if the molecules are able to move past one another with minimal resistance. Strong intermolecular attractive forces make it more difficult for liquid molecules to move with respect to one another, leading to higher viscosity values. London dispersion forces increase with chain length.

A relationship also exists between viscosity and molecular shape. Liquids with longer, more flexible molecules tend to have higher viscosities than those composed of more spherical or shorter-chain molecules. Longer molecules can also become entangled with one another, making it more difficult for them to move past one another.

'Two-plates' model

The two-plates model offers a way to describe viscosity mathematically. Consider two imaginary plates parallel to each other, with fluid between them (Figure 1). If a force (shear force) is applied to the upper plate over a space with area *A*, while the lower plate remains stationary, the layer of fluid just below the plate moves with it. For the purpose of the model, it is assumed that the fluid sample adheres to the plates, and the flow is imagined to be laminar, in the form of layers of fluid without turbulence.

The force required to effect the shearing is known as shear stress, often expressed as the symbol tau (τ). The units of shear stress are Pascals (N/m^2). The shear rate ($\dot{\gamma}$) is the rate of deformation of the liquid as a result of shear stress). Shear rate (with units of s^{-1}) is thought of as velocity (m/s) over the distance between the plates (h).

$$\text{Shear stress: } \tau = F / A \quad (1)$$

$$\text{Shear rate: } \dot{\gamma} = v / h \quad (2)$$

The ratio of applied shear stress to the resulting rate of shear, Viscosity units are the poise (mPa·s). A related parameter is yield stress, the amount of force required to get a material to begin flowing.

Newtonian vs. non-Newtonian

Fluids that are ideally viscous (Newtonian fluids) have constant viscosity for all shear-rate values (Figure 2). Water and hydrocarbons often exhibit Newtonian behavior. For shear-dependent fluids, on the other hand, the viscosity varies. Because of this, the shear rate at which the viscosity was determined needs to be specified. This is known as apparent viscosity.

If a fluid's apparent viscosity is not constant at a given temperature and pressure, but is dependent on flow conditions, such as flow geometry, shear rate and others, then the fluid is said to behave in a non-Newtonian manner. For many industrial applications, expressions of viscosity as a single value fail to capture the full picture of the many factors that affect viscosity. Non-Newtonian viscosity behaviors include the following:

Pseudoplasticity (shear-thinning) occurs when a fluid's viscosity decreases with increasing shear rate. Many emulsions, polymer melts and solutions, paints, blood and some solid suspensions exhibit this property.

Dilatant (shear-thickening) fluids show increasing viscosity with increasing shear rate. Dilatant behavior is observed in starch suspensions in water, quicksand and in some high-molecular-weight polymers used in drilling muds.

Thixotropy is a situation where a fluid's viscosity decreases over time under constant shear stress. Clay suspensions used as drilling muds, mayonnaise and some paints and inks behave this way.

Rheopecty refers to a materials that show a rise in viscosity as a result of consistent agitation. Some lubricants exhibit this property, as does heavy cream. A gypsum suspension in water is another example.

A flow curve (rheogram) is a graphical representation of how a flowing material behaves when subjected to increasing or decreasing shear rates (Figure 2). Newtonian fluids have a linear flow curve with a slope intercept at zero. Non-Newtonian fluids have non-linear flow curves and often a non-zero intercept. ■

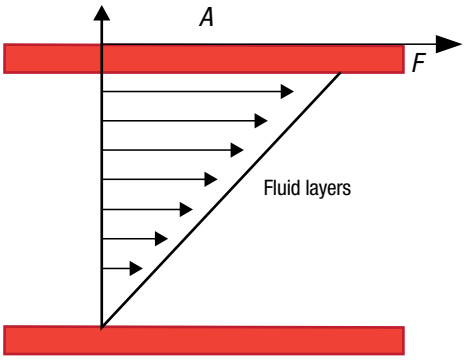


FIGURE 1. A force applied to the top plate will effect shearing in the fluid below

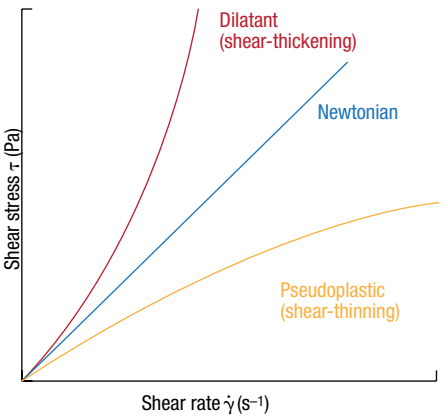


FIGURE 2. Newtonian fluids show constant viscosity for all shear-rate values, while non-Newtonian fluids show divergence

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Introduction to Activated Carbon

Understanding the different types of activated carbon products, their specific properties and best practices for use is essential to the design of effective environmental treatment processes

Martin O'Brien, Rebecca DiStefano and Andrew Harris
Calgon Carbon Corp.

IN BRIEF

HOW ACTIVATED CARBON IS MADE
HOW ACTIVATED CARBON IS USED
LIQUID-PHASE BEST PRACTICES
VAPOR-PHASE BEST PRACTICES
SPENT MEDIA AND REACTIVATION
SYSTEM DESIGN AND SCAELUP
SAFETY

Activated carbon is a type of manufactured carbon material used for a range of adsorptive processes, including drinking water treatment, industrial operations, environmental remediation and many other applications. Reports suggest that crude activated carbons have been used in various ways for millennia, for example by ancient Egyptians and Romans as medicine or for water filtration, but the science of more effective modern activated carbons has been continuously developing over many decades. Today's activated carbon products include cutting-edge manufactured materials that are crucial to society's water and energy infrastructure, as well as modern industry. Activated carbon provides an environmental solution for ensuring clean air and drinking water and contributes to the efficient production of many industrial products. Understanding the different types of activated carbon products, their specific properties, and best practices for use is important to the design of effective treatment processes.

Activated carbon is ubiquitous because it is a versatile adsorbent material with the ability to separate and retain components of many liquids and gases (Figure 1). Within an activated carbon particle, the immense specific surface area facilitates the physical adsorption of molecules onto the carbon surface. In contrast to absorption, where fluids enter the internal area of a material, causing it to expand, adsorption is a phenomenon that describes how molecules physically adhere to a surface. Physical adsorption onto activated carbon occurs through weak intermolecular forces called Van der Waals forces in the internal surface area of carbon, often called the pores of the carbon, which give activated carbon its exceptional ability to adsorb and retain organic compounds. Activated carbon adsorption is non-specific and the adsorbate properties contribute to practical capacity for a given contaminant. The adsorption strength of a compound onto activated carbon increases with molecular weight and aromaticity, and can be influenced by functional groups. This adsorptive capability allows activated carbon to be utilized in a wide range of separation processes. Some common factors that affect adsorption are detailed in Table 1.

How activated carbon is made

Activated carbon is manufactured by carbonizing a carbon-rich material and then generating new internal surface area in a process called activation. The type of activation process used and the selected raw materials will produce finished activated-carbon products with different properties.

There are two types of activation processes used to generate internal surface area: physical activation, which uses a high-temperature gas, such as H_2O or CO_2, to react with carbon to increase surface area; or chemical activation, which produces surface area by reaction of carbon sources with an added chemical, such as HP_3O_4. Physical activation with H_2O vapor is the most common activation process practiced industrially, but chemical activation is

FIGURE 1. Activated carbon is used in treatment processes when manufacturing a wide variety of industrial products, as well as in environmental treatment for water, air and more

used to produce some specialty activated-carbon products.

Worldwide, many raw materials are used to manufacture activated carbon, but the most industrially significant sources of activated carbon are coals, ranging from low-rank coals like lignite, to higher-rank bituminous and anthracite, as well as biomass-based sources, such as wood and coconut shell. The respective raw material used will produce an activated carbon with some properties inherited from the raw material, including adsorptive properties, such as the pore structure (or pore distribution), as well as physical properties like inorganic mineral components, termed ash content, and the hardness of the resulting activated carbon. The selected carbon source influences the physical and adsorptive characteristics of the finished activated carbon product, making different carbons suitable for different applications. Coconut shells and high-rank coals, such as bituminous material, yield denser, harder activated carbons and have low ash content with more microporous pore structures. Wood feedstocks and low-rank coals, such as lignite, yield softer activated carbons with more mesoporous and macroporous structures. The base material can often have a major impact on carbon performance for a given application. For example activated carbons produced from bituminous coal sources adsorb per- and poly-fluoroalkyl substances (PFAS) better than carbons produced to similar specifications from coconut shell sources.

Activated carbon products can be manufactured as granular activated carbon (GAC), in the millimeter particle-size range, as powdered activated carbon (PAC), typically consisting of particles falling below 44 micrometers (μm), or in other forms, such as pellets and cloth. Figure 2 shows the different formats and provides specific properties for each.

Properties and specifications. Specifying the properties for activated carbon is crucial, because specifications ensure that the carbon product will perform as expected for its intended application, and that it is of a consistent quality. Because activated carbon is used in a wide range of industries, including water treatment, air purification and food-and-beverage processing, the specifications that make an optimal carbon product may vary by application. Table 2 describes several typical specifications for activated carbon.

How activated carbon is used

The way activated carbon is used highly depends on the form of carbon chosen. The most common way activated carbon is used is in a packed bed, where GAC is placed in a stationary vessel, and a stream of liquid or gas flows through it. This allows the GAC to adsorb contaminants from the fluid, retaining them within the GAC particles. Packed beds of GAC are widely used in the water-treatment industry to remove organic compounds from drinking water, in wastewater treatment and in liquid chemical processes. Similarly, for air and industrial-gas treatment, packed bed systems are used to remove pollutants, such as volatile organic compounds (VOCs) or H_2S. Packed bed systems allow for relatively simple operations using GAC in both liquid- and vapor-phase applications, and the packed beds themselves are often designed with ease of media installation and removal in mind. Typically, activated carbon is used as a polishing technology for relatively low concentrations in the liquid and gas phase, rather than used in concentrated streams, though there are exceptions.

PAC is too fine to be retained within a packed bed, and instead is typically added to a liquid stream in a batch process, in which the carbon

TABLE 1. COMMON FACTORS THAT AFFECT ADSORPTION

Property	Effect on liquid-phase adsorption	Property	Effect on vapor-phase adsorption
Solubility	The higher the solubility, the more difficult to adsorb	Concentration	Wt. % loading on carbon increases as inlet species concentration increases
Concentration	Wt. % loading on carbon increases as inlet species concentration increases	Saturation pressure	The closer to saturation pressure, the more strongly adsorbed
Molecular weight	The higher the molecular weight, the better adsorbed	Relative humidity (RH)	RH above 50% interferes with adsorption efficiency — lower adsorption capacity
Functional groups	More complex structures adsorb more strongly	Temperature	Higher temperatures result in lower wt. % loading

TABLE 2. TYPICAL ACTIVATED CARBON SPECIFICATIONS

Specification	Unit	Description
Mesh size	Mesh	The size of the carbon particles, measured in the percentage of particles existing between the U.S. mesh sizes denoted, such as 8x30 or 12x40
Iodine number	mg/g	A surrogate measure of the surface area of the carbon, with higher numbers indicating greater surface area available for adsorption
Hardness	%	A measure of the carbon's resistance to breakage or abrasion, with higher percentages indicating greater durability
Ash content	%	The amount of inorganic material present in the carbon, which can affect its performance in certain applications
Moisture content	%	The amount of water present in the carbon, which can affect its performance and handling characteristics
Apparent density	g/cm^3	The weight of packed carbon per unit of volume, which can affect its handling and transportation costs

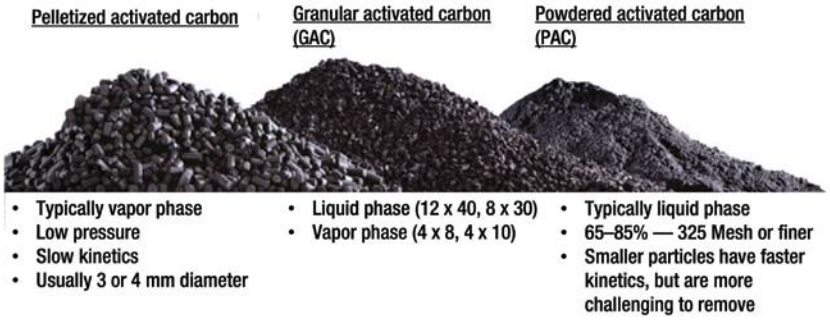
Pelletized activated carbon
Granular activated carbon (GAC)
Powdered activated carbon (PAC)
• Typically vapor phase
• Low pressure
• Slow kinetics
• Usually 3 or 4 mm diameter
• Liquid phase (12 x 40, 8 x 30)
• Vapor phase (4 x 8, 4 x 10)
• Typically liquid phase
• 65–85% — 325 Mesh or finer
• Smaller particles have faster kinetics, but are more challenging to remove

FIGURE 2. There are multiple formats for activated carbon products, each with a unique set of properties

particles are dispersed into the fluid and allowed to adsorb the contaminants. After the adsorption process, the PAC particles are filtered out of the fluid, typically using a mechanical filtration system. PAC can also be injected into vapor streams and removed in particulate capture devices, such as baghouses, a practice used for the removal of VOCs and dioxins, furan and mercury from fluegases.

While PAC particles have larger external surface area than GAC, there is no significant difference in specific surface area between GAC and PAC, because the majority of activated carbon's surface area is internal. Adsorption kinetics onto activated carbon are dependent on particle size, and the small particle size of PAC results in rapid adsorption kinetics, allowing PAC to adsorb compounds at a faster rate than larger particles of carbon.However, there is no difference in the equilibrium loading of GAC and a corresponding PAC produced to an equivalent adsorption specification. Indeed, packed beds of GAC often result in better carbon usage rates than PAC. Practically, GAC used in a packed bed system often loads to a higher degree than PAC, adsorbing more contaminants per mass of carbon used.

Liquid-phase best practices

GAC liquid adsorbers can be used with single vessels, but designs commonly include multiple adsorber vessels operating in series flow, lead-lag configuration, to allow for the greatest utilization of GAC capacity. In this configuration, when the lead vessel has reached its capacity, the lag vessel is moved into the lead position and a fresh carbon bed is put online in the lag position. Typically, at least ten minutes of empty bed contact time (EBCT) per vessel are required to account for the kinetics of adsorption and provide for an adequate bed life, depending on contaminant inlet concentrations and treatment objectives. In general, longer contact times are required as the carbon particle size increases and as the fluid viscosity increases. Decreasing the flowrate through a given vessel will reduce and sharpen the mass transfer zone (MTZ) of the bed, increasing carbon loading. Additionally, pretreatment and operational maintenance (such as backwashing) may be warranted in some applications, some of which are detailed in Table 3.

Vapor-phase best practices

Vapor-phase adsorption applications with activated carbon differ significantly from liquid-phase applications in that the required contact time is often much less in the vapor phase, due to the kinetic advantages associated with gas adsorption. For high removal across a vapor-phase carbon bed, typically three or more seconds of contact time are required. Because adsorption is an exothermic process, and in vapor-phase applications there is not excess water present to dissipate heat, there are some guidelines for

TABLE 3. TYPICAL LIQUID PRETREATMENT AND OPERATIONAL GUIDELINES FOR GAC SYSTEMS

Parameter	Pretreatment recommendations and operational considerations
Total organic carbon (TOC)	• Adsorbable TOC consumes carbon capacity, so lower TOC results in lower carbon usage rates. GAC can tolerate greater than 1,000+ parts per million (ppm) TOC, depending on application
Total suspended solids (TSS)	• TSS will foul beds and block access to carbon pores • Upstream filtration of 5–10 µm is recommended • Backwashing may be required for TSS in the 3–5 mg/L range, otherwise solids can cause increased ΔP
Total dissolved solids (TDS)	• Application-dependent, though typical hardness < 100 mg/L for water treatment
Manganese	• <0.5 ppm
Iron	• <1 ppm
Chlorine (or other oxidizers)	• <5 mg/L
Oil and grease	• If not fully dissolved or in solution, remove upstream of GAC • Do not use GAC to directly treat two-phase systems or free product containing water
Langelier Saturation Index (LSI)	• Avoid corrosive or saturated conditions • Neutral or negative LSI desired to avoid Ca or Mg buildup
Bacteria	• Backwashing can help mitigate biofouling; caustic solution disinfection recommended for inoculated carbon beds
Linear velocity	• The superficial velocity of the liquid stream as it passes through the carbon bed is calculated as the volumetric flow rate of the stream divided by the cross-sectional area of the carbon bed • The linear velocity should be carefully controlled to prevent channeling (velocity too low) or excessive pressure drop (velocity too high). Guidelines for linear velocity in liquid-phase applications typically range from 2 to 9 gal/min/ft^2.

TABLE 4. TYPICAL VAPOR-PHASE GUIDELINES AND OPERATING CONDITIONS

Design requirement/parameter	Description
Particulate matter and aerosols	• As in liquid-phase applications, GAC will physically filter some particulate matter, but since backwashing is not typically possible in vapor-phase applications, it is recommended to remove particulate matter prior to the carbon bed to prevent their buildup and associated issues, such as channeling • GAC will not adsorb aerosols in the same way it adsorbs gases
Linear velocity	• The superficial velocity of the airstream as it passes through the carbon bed is calculated as the volumetric flowrate of the airstream divided by the cross-sectional area of the carbon bed • The linear velocity should be carefully controlled to prevent channeling (velocity too low) or carbon fluidization and vibration (velocity too high). Guidelines for linear velocity in vapor-phase applications typically range from 15 to 90 ft/min
Length/diameter (*L*/*D*) ratio	• The ratio of the bed length (depth) to the bed diameter. *L*/*D* is important because it affects the flow distribution of the air stream through the carbon bed, which in turn affects the efficiency of the adsorption process • In general, a higher *L*/*D* ratio leads to better flow distribution and more efficient adsorption, but also increases pressure drop and energy requirements • *L*/*D* ratio of 3 to 5 is typically recommended to balance efficiency and pressure drop considerations. Typically, at least several feet of bed depth are used
Humidity	• The moisture content of the vapor stream being treated must be considered. This parameter is important because moisture can compete with the target species for adsorption sites on the carbon • Relative humidity (RH) above 50% can negatively impact VOC adsorption
Pressure drop (ΔP)	• Pressure drop is the decrease in pressure that occurs as the vapor stream passes through the carbon bed. This parameter is a function of the flowrate of the vapor stream, bed design, carbon type and the gas properties • Smaller-sized carbon particles will cause higher pressure drop and require greater energy to overcome the pressure drop across the bed

reducing thermal risk in these applications. Typically, inlet concentrations of VOCs exceeding 1,000 ppmv in air are not recommended. Additionally, some compounds, such as ketones and aldehydes, can oxidize on the carbon by atmospheric oxygen, generating additional heat, and so their inlet concentrations should be limited. Additional vapor-phase design and operating considerations are included in Table 4.

Spent media and reactivation

After activated carbon has reached its capacity and will no longer adsorb the target chemical species, it often must be removed from service. In packed beds using GAC, the spent GAC is removed from the adsorber vessel by vacuum or by slurry method, depending on the vessel design and utilities. Spent GAC is moved by truck and can be disposed of by landfill or incineration. A more environmentally friendly and cost-effective approach is to reactivate the spent activated carbon.

Carbon reactivation is a process where spent, contaminant-loaded GAC is returned to a facility with a suitable reactivation furnace, which operates under similar high-temperature conditions to physical carbon-activation furnaces. In the carbon reactivation furnace, contaminants are desorbed from the GAC and destroyed, and the furnace atmosphere facilitates the generation of new surface area in the GAC. A downstream abatement process ensures adequate destruction, control of acid-gas generation, and particulate-matter removal. Thus, the carbon reactivation process removes and destroys contaminants from GAC, allowing for the GAC to be re-used in the same or other processes. Reactivation is typically only practiced on granular materials with sufficient hardness and density to resist physical degradation in the aggressive furnace atmosphere.

To be eligible for carbon reactivation, the material must undergo a "Carbon Acceptance" process, where the composition of the carbon and contaminants are verified as acceptable. Carbon reactivation has proven to be effective at removing and destroying even robust compounds, such as PFAS. Ref. 1 describes a peer-reviewed study demonstrating >99.99% destruction of total PFAS compounds across a carbon reactivation furnace.

System design and scaleup

System design and performance of GAC adsorbers is dependent on several factors, but key details include targeted adsorbate species, stream composition, inlet concentrations and outlet concentration goals. There are several methods that can be used to inform the design and determine the expected performance of a larger GAC system, and they are ranked in the order of increasing accuracy.

Computational models. Technical industry experts can use computational models to estimate the performance of carbon in various applications, inputting key factors, such as stream properties and composition, selected model sorbents and so on. These can be effective for some target species and applications, but have less value than empirical data generated using source waters and chosen sorbents.

Isotherms. Isotherm testing measures the adsorption capacity of a sorbent by plotting the mass of adsorbate loaded on carbon against its concentration at a constant temperature and is often performed at bench scale with selected sorbent products and source waters. An isotherm can inform the theoretical maximum capacity of a sorbent for a selected adsorbate. While isotherms are useful at determining feasibility for an application, they do not accurately model full-scale adsorber systems and cannot determine component breakthrough order

or time.

Laboratory column testing. Small column testing can be performed at bench scale to simulate the longer-term performance of a full-scale system. Two common methods include the Rapid Small-Scale Column Test (RSSCT) and Accelerated Column Test (ACT), where GAC is carefully resized to a determined smaller particle size, allowing for the simulation of months of full-scale system run time in just days. Laboratory column testing can be more reliable than isotherms and can provide better details about component breakthrough order and estimated days until breakthrough.

Pilot systems. Pilot systems consist of small vessels located onsite at the application, treating a slipstream or representative sample of the target source stream. Pilots can be designed to more closely replicate the conditions of a full-scale system and, coupled with representative pretreatment, are the most reliable method for determining full-scale system performance.

Some GAC and equipment vendors offer rental equipment, which includes carbon-exchange services, including removal of spent GAC from the vessel, disposal and replacement with fresh GAC. Rental units can be particularly good options for pilot systems, and some rental equipment units are designed so that the entire unit can be returned to the provider for carbon reactivation or disposal, simplifying media exchange.

Safety

Activated carbon is generally a safe technology, especially when used in well-designed systems. However, there are a few safety considerations that are worth highlighting.

Wet activated carbon preferentially removes oxygen from air. In closed or partially closed containers and vessels, oxygen depletion may reach hazardous levels. If workers are to enter a vessel containing carbon, appropriate sampling and work procedures for potentially low-oxygen spaces should be followed, including all applicable federal and state requirements.

In vapor-phase applications, high concentrations of VOCs and some reactive components can cause the temperature within a carbon bed to increase. Heating may be controlled by diluting the inlet air with nitrogen or by pre-wetting the carbon. Concentrations of gases should be kept to below 25% of the lower explosive limit (LEL). Seeking input and advice from an activated carbon supplier for applications involving high concentrations of organic compounds or potentially reactive species (certain ketones, aldehydes and carboxylic acids) is highly recommended. ■

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Reference

1. DiStefano, R., others, Thermal destruction of PFAS during full-scale reactivation of PFAS-laden granular activated carbon, *Remediation*, Vol. 32, Issue 4, September 2022.

All images provided by Calgon Carbon Corp.

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A Boundless Future for Process Control in the CPI

Emerging automation-system architectures will provide the foundation required for optimized operations across the enterprise

Claudio Fayad
Emerson

IN BRIEF

NEW NEEDS
CHANGING NEEDS, NEW ERA
OLD STRATEGIES STRUGGLE
INTEGRATING OPERATIONS
UNIFIED SOFTWARE ECOSYSTEM
A SINGLE TECHNOLOGY STACK
MULTIPLE DOMAIN OPTIMIZATION
PREPARING FOR THE FUTURE

For decades, when a person mentioned process control, most engineers' minds went to proportional integral derivative (PID) loop control, interlocks, safety and advanced process control. Perhaps even more in the chemical process industries (CPI) than many others, the ability to manage these aspects of control, and correctly configure them, has been the key component to improve operations, and as such, the main criteria in selecting control systems. Users were laser focused on designing systems that ran individual plants as efficiently as possible, and these tools were integral to those efforts.

Of course, part of keeping those systems efficient and effective was isolating them from intentional and unintentional interference. As a result, engineering teams employed the Purdue model and segregation of systems to ensure the control system was isolated in its own layer, and — perhaps most importantly as technologies advanced — isolated from the internet. At the time, plants were frequently instrumented for control only, and that model of control worked well for safe, efficient operation of individual facilities. Engineers focused on ensuring instruments could communicate with PID controllers. Control capabilities and optimal human-machine interfaces were therefore key criteria for selecting technologies.

Even in the most forward-thinking plants — those applying advanced process control strategies and technologies — the control system was still isolated within its own layer in the Purdue model. Communication occurred among different control technologies in different process units, but that communication was carefully managed and tightly controlled. Systems worked well and were safe, but they were not necessarily prepared for impending changes, particularly a connected future of self-optimizing plants, a shrinking workforce, and shifting business and public expectations. These and other trends upended process manufacturing across the span of only a few years.

New needs

For years, teams have considered sustainability initiatives, energy management and, in some cases, even predictive-reliability improvements to be burdens at odds with production. However, these needs are simply high-level optimization problems, with each requiring teams to look at process control and operations in a more holistic way.

Much of this struggle stems from the fact that, for decades, automation — often because of rigid design structure — has been implemented plant by plant or unit by unit, leaving a wide variety of systems all operating independently. Many process plant teams have long since maximized the gains from such a strategy. But sustainability, energy and reliability initiatives are refocusing efforts on optimizing the entire fleet or enterprise to capture previously unnoticed or undervalued synergies.

For a company with multiple plants manufacturing the same product, a focus on enterprise optimization typically results in significant gains from balancing production based on equipment status or green energy availability. Or, for companies with limited personnel, enterprise optimization can make it easier to move people and products from one site to another, creating consistency among plants to improve efficiency. But all these strategies require the implementation of modern and upcoming advanced automation technologies.

Changing needs, new era

Today, the process control landscape is rapidly changing. As shifts in corporate and public opinion have increased focus on reliability, sustainability, energy use and more, operations teams are rapidly transforming the way they design, build and operate their fleet of plants. With those changes come new needs (Figure 1).

Increased production now rarely comes from simply deploying a new plant to manufacture more product, and costs are higher and demand is more volatile than ever before. As a result, companies are much more

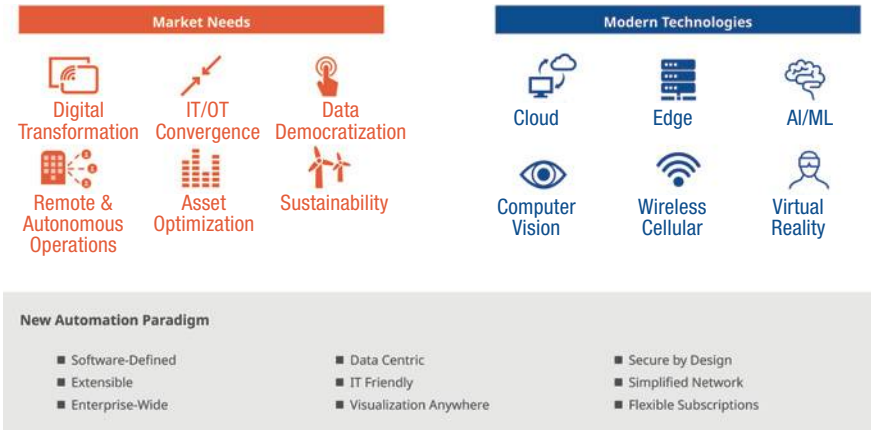

FIGURE 1. New market needs have created an inflection point, along with a corresponding demand for a new automation paradigm

cautious about approving capital expenditures for new plants across a fleet. Moreover, building a new plant requires more people to operate it — and experienced people are becoming harder to find.

Instead, today's successful companies are focused on optimizing existing assets. But because many plants have been optimizing their local operations for years, accomplishing a true paradigm shift in operations requires an expanded vision. The most successful organizations are optimizing from an enterprise level to drive improvements, with more confidence in the strategies their teams implement to achieve these objectives.

For example, more and more teams are identifying a need for advanced analytics to optimize operations across their fleets. By leveraging artificial intelligence (AI) and machine learning (ML), analytics technologies provide guidance for holistic optimization. Data from a robust suite of sensors, software and control technologies enable companies to optimize the business and sustainability performance of their plants and enterprise through advanced asset and business optimization software.

Similarly, many teams are finding a need to employ powerful simulation software to identify, design and test process changes to optimize operations. Simulation software empowers enterprise teams to use design models to identify potential changes and improvements across an organization's facilities.

Many teams further improve on the gains of simulation with digital twin software, replicating entire plants to see how changes to improve reliability, sustainability and energy use will cascade across all areas. And when optimization is complete, those same digital twins are used to train operators on the new processes (Figure 2).

Typically, these new systems (and their associated integration with business systems) also create a need for cloud connectivity. But letting control systems touch the internet introduces a wide array of cybersecurity concerns. In the past, those concerns were alleviated by completely isolating the control system from the outside world. Today, however, as cloud connectivity becomes a need rather than a desire, operations teams are flattening the Purdue model to simplify and enable external connectivity. As they do so, they dramatically increase their need for more cybersecure, data-centric solutions.

Old strategies struggle

At the heart of making all these new strategies work are data, and operations teams are rapidly bringing in the technology necessary to gather those data, add value to it, and make it easy to access and use. Input/output (I/O) points are expanding, with many plants adding three to ten times the number of I/O points they had only five or ten years ago, many of them inputs from wireless instruments. A vast new array of intelligent field devices is providing companies with access to far more data than ever before, but only if they can harness the data effectively.

Creating value from data is difficult using legacy automation strategies. Often, teams are hesitant to connect intelligent field devices used outside process control into the existing distributed control system (DCS) because of the cost of the DCS infrastructure. To avoid the extra cost, operations teams instead design new infrastructure to collect and move data where they need it, which in turn increases complexity and creates new silos.

Creating new infrastructure introduces its own set of problems, however. Most importantly, when process data bypasses the control system, it loses all the critical contextual metadata the control system can provide, which is often needed to turn raw data into valuable information. Data without context can potentially be helpful if it is used immediately and locally, but over time and when aggregated, the data becomes less valuable.

Moreover, every time the team creates a new infrastructure for moving data, they create a new data silo. Such a data set may be useful in a single reliability tool or edge analytics package, but it is typically not available across the enterprise to the other users and cross-functional teams that might otherwise be able to use it.

Relying on these legacy strategies puts operations teams in a no-

FIGURE 2. A digital twin can replicate an entire plant, empowering operations teams to test and train on new operations strategies to improve performance, without the risk or downtime of using live equipment

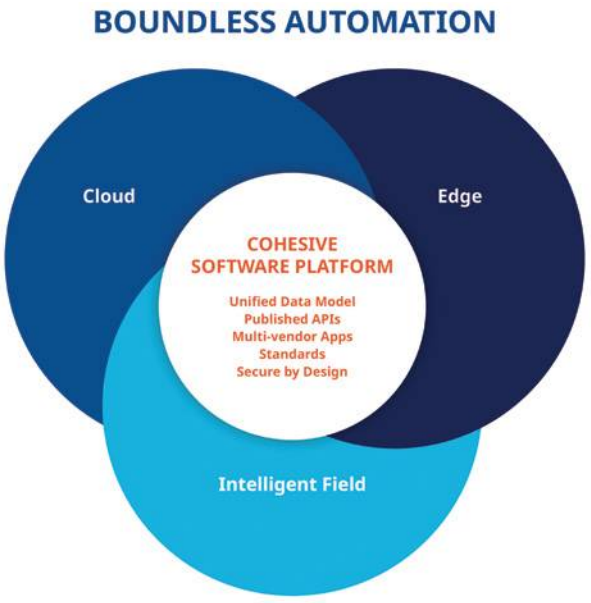

FIGURE 3. As organizations embrace more automation connectivity across their enterprise, the isolated architectures of the past are making way for an integrated, cohesive boundless automation architecture based on the next generation control system

win situation. They lose the critical context of their data and create additional silos, inhibiting access and making it harder to use data effectively for meaningful optimizations. And while teams can layer edge solutions over siloed architectures to help move data where it is needed, those types of solutions do not address the core problem of creating a truly connected system to seamlessly move data sets where teams need them without losing any context.

To meet those more holistic needs, today's forward-thinking automation providers are breaking down the boundaries around automation technologies by expanding the next-generation control system to incorporate all essential operational domains.

Integrating operations

To truly get the most benefit from automation, organizations need an architecture that will seamlessly integrate the software, tools, technologies, data and controls of a next-generation automation stack across every operational domain, from the field to the edge to the cloud. Driving this type of holistic optimization, necessary to compete in a global market, will require more than complex independent edge architectures to collect, standardize and democratize data.

Innovators leveraging a boundless automation vision will use technology across every domain — reliability, sustainability, energy use, quality and more — to perform optimization across the enterprise. Much like enterprise business solutions, boundless automation will eliminate silos through a scalable, interoperable, and extensible unified data model (Figure 3).

To accomplish this vision, innovative organizations will shift their operations strategies to embrace digital transformation technologies that expand automation and control to encompass all process automation needs. They will begin implementing next-generation DCS technologies that have evolved to become enterprise automation platforms, without giving up on core process control. Control will still be a strong core competency, but it will be one of the functions manipulating and modifying contextualized field data.

While much of this boundless automation future is focused on advancements beyond the horizon, the building blocks are visible today, and they provide a roadmap to help organizations prepare for the brave new world of automation that is rapidly approaching.

Unified software ecosystem

New technologies and applications combined with market needs — including "born digital" companies, decentralized operating models, and the move toward self-optimized plants — have created demand for a new automation paradigm where a unified software environment streams data across the enterprise effortlessly, when and where it's needed. Today's operators expect intuitive, integrated software platforms, much like the solutions that revolutionized business software ten or fifteen years ago.

As teams begin to build an automation architecture comprehensive of all domains, they will rapidly eliminate segmentation. All operational domains will be integrated into a single, cohesive software ecosystem, with information from intelligent field devices, edge systems, and the cloud all coming together as part of a cohesive data model. Essential data will be democratized — standardized in format and laden with context — for easy collaboration among cross-functional teams. Moreover, that same data will be securely available on demand to authorized people across the enterprise, anytime from anywhere in the world.

A single technology stack

Modern architectures, technologies and protocols — such as Ethernet advanced physical layer, 5G communication, OPC UA, hyperconverged infrastructure, containerization and Kubernetes — are creating a bridge between operational technology (OT) and information technology (IT), enabling easier connectivity and more data flow.

For example, smart sensors can perform more tasks right at the asset and pass large amounts of data directly to process control, and send data to reliability and analytics software hosted at the edge or in the cloud. Not only do these new technologies improve visibility and decision making at the enterprise level, they also assist operations teams in their efforts to improve operations. Teams will be able to use new, critical information from the field to make better decisions and continuously improve efficiency.

Miltiple domain optimization

While most modern plants can optimize their own operations domain by domain, boundless automation architecture creates a framework for tensioning multiple domains against each other simultaneously to deliver enterprise-wide optimization. A unified software platform combined with next-generation automation systems will help organizations continue to digitally transform their operations through an intuitive ecosystem of

seamlessly interconnected technologies from the intelligent field across the edge and into the cloud. Every piece of operations-relevant data will flow securely from any operations domain to all relevant OT functions in the ecosystem.

Cross-functional teams from all levels of the organization will be able to instantly access that democratized and contextualized data. When needed, these data can be fed to artificial intelligence and machine learning systems, simulations and digital twins, reliability and energy monitoring, and other solutions hosted on premises or in the cloud. Using this deep well of critical data, teams will be able to develop the control strategies necessary to ensure peak performance, drive more sustainable operation, lower energy use, and begin the move toward autonomous operation.

Preparing for the future

Today's automation technologies are purpose-built for improved performance, but often leave out domains critical to modern, efficient, fully optimized operation. In most cases, this disconnect happens because data in those domains are stranded, or accessible only through custom overlay architectures built at the edge. But the newest automation technologies on the market today, as well as those coming in the years ahead, will change that paradigm.

Operators want comprehensive, unified solutions that deliver consistency and ease of use, and forward-thinking automation providers are modernizing control systems to meet that need. Tomorrow's automation architecture will dramatically expand to encompass all domains, providing highly contextualized data that are standardized for use by any authorized person or system, anywhere and at any time.

As more companies modernize their automation systems to deliver the flexibility, standardization, and visibility necessary to meet a future more focused on malleable, sustainable operation, they are changing the criteria by which they evaluate the technologies that will carry them into the future. Efficient, effective control is no longer enough. Fully optimized operation across the enterprise will require an automation vision for industrial architecture that integrates all of operations, using next-generation tools to make the most of data. ■

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All figures courtesy of Emerson

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Industry Adoption of Open Process Automation

Presented here is a description of the Open Process Automation Standard and a progress report on its implementation by industry

R. Donald Bartusiak
Collaborative Systems Integration, Inc.

IN BRIEF

OPA OVERVIEW
INDICATORS OF INDUSTRY ADOPTION
EXAMPLE: COPA QUICKSTART
CONCLUDING REMARKS

Open Process Automation (OPA) is an end-user company-driven industry movement to transform the industrial control-system market from one that supplies closed, proprietary products to another that supplies open, secure, interoperable systems derived from a standards-based automation architecture. OPA addresses the root causes of end-user pain points. The top three business drivers for end-users companies are the following:

1. Increase operational benefits from improved capabilities
2. Improve cybersecurity compared to currently available systems
3. Reduce the system's capital and lifecycle costs

OPA is primarily targeted at the chemical process industries (CPI) — continuous, semi-continuous and batch — across multiple industry sectors.

OPA is based on an industry standard (O-PAS) that is being defined by the Open Process Automation Forum of The Open Group (OPAF). The business case for action, mechanisms of value generation, and discussions of stakeholder concerns are documented in the *Open Process Automation Business Guide* [*1*]. A more detailed discussion of concerns and next steps towards OPA for end-user and system-integrator companies is provided in the *OPA Adoption Guide* [*2*]. (An extension for the *OPA Adoption Guide* for supplier and service provider companies is currently being written).

To make the business problem real, particularly for end-user readers, one of the specific motivations for the OPA initiative was to find a game-changing improvement to the prospect of hundreds-of-million-dollar costs per manufacturing site for control-system upgrade projects that offered little, if any, return on investment.

In this article, we first provide a brief overview of the Open Process Automation Standard (O-PAS), the business ecosystem, and conformance certification of products to the O-PAS standard. Second, information on the maturity and industry adoption of OPA is presented. Third, an example of a commercially available OPA system, QuickStart from the Coalition for Open Process Automation (COPA), is discussed.

OPA overview

The Open Process Automation Forum was founded in November 2016 and currently consists of 112 member organizations — end user, hardware and software supplier (including all but one of the major distributed control system (DCS) and programmable logic controller (PLC) vendors), and system-integrator companies, as well as several universities. OPAF also has liaison relationships with standards organizations and industry associations, including NAMUR, OPC Foundation, Control System Integrators Association, International Society for Automation, and others.

The OPA reference architecture is presented in Figure 1. The three essential object types in the OPA architecture are (1) Distributed Control Node (DCN) with input/output (I/O) Node, Compute Node and Gateway

TABLE 1. O-PAS PART DOCUMENTS, SUBJECT MATTER AND REFERENCED INDUSTRY STANDARDS

O-PAS Part	Subject matter	Referenced standard
Part 1	Technical architecture	IEC 62264 (ISA 95)
Part 2	Security	IEC 62449 (ISA 99)
Part 3	Profiles	not applicable
Part 4	Connectivity framework	IEC 62541 (OPC UA)
Part 5	System management	DMTF (Redfish)
Part 6 (.1 – .6)	Information and exchange models	IEC 62714 (AutomationML) IEC 62682 (ISA 18) IEC 61131 IEC 61499
Part 7	Physical platform	"whitespace", PCMIG
Part 8 (future)	Application portability	containerization
Part 9 (future)	System orchestration	OASIS (TOSCA)

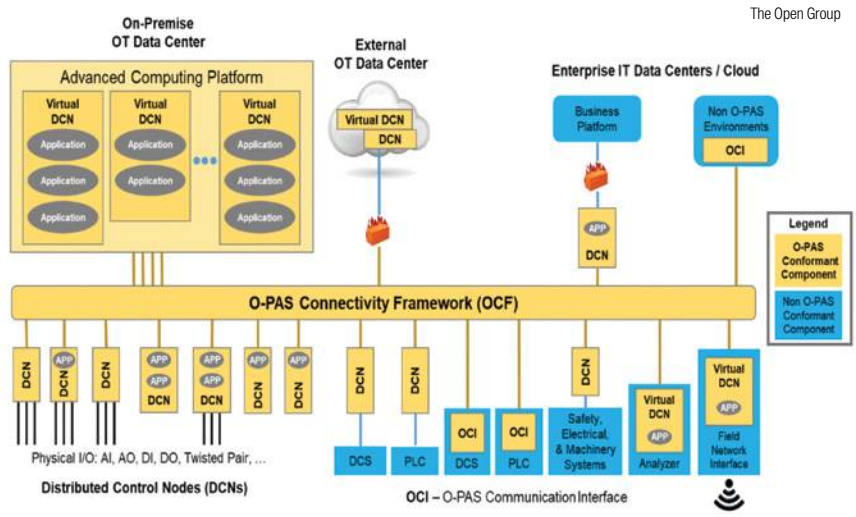

FIGURE 1. The OPA reference architecture is shown here

Node profiles; (2) O-PAS Connectivity Framework (OCF) for networking and data communications; and (3) Advanced Compute Platform (ACP), an on-premise, low-latency, high-availability compute platform with greater CPU and memory resources than typical DCNs.

Industry standard. O-PAS is a "standard of standards," meaning that existing industry standards are referenced when they are fit-for-purpose. Only if no standard is available or suitable is new standard development undertaken. Table 1 lists the O-PAS Part documents and referenced standards.

Business ecosystem. The business ecosystem for OPA is depicted in terms of stakeholder roles in Figure 2.

The rectangles in Figure 2 depict roles, not companies. A company can play multiple roles in the ecosystem. The blue lines symbolize contractual relationships and loose, cohesive couplings between modules based on open standards.

Conformance certification. O-PAS specifies conformance requirements (normative "shall" statements) that are organized into collections called profiles. An O-PAS product is a hardware or software module consisting of one or more profiles. Particularly for the benefit of suppliers, policies for product conformance certification are specified by OPAF in the *O-PAS Certification Policy* [3].

The Open Group is the O-PAS Certification Authority. O-PAS conformance verification testing will be performed by several independent third-party organizations, such as the OPC Foundation, the ISA Security Compliance Institute, and others.

The profiles that are included in

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the initial round ("Wave 1") of O-PAS conformance certification are listed in Table 2.

Preliminary testing of O-PAS conformance certification Wave 1 has been underway for about a year with multiple suppliers. This preliminary testing is non-binding. It gives the suppliers the opportunity to vet their products for conformance, and it gives OPAF and the Verification Lab the opportunity to validate the conformance test cases and testing tools.

O-PAS Conformance Certification Wave 1 is scheduled to begin operations in mid-2023.

Indicators of industry adoption

Measuring the effectiveness of innovation is a notoriously difficult thing to do and any rigorous discussion of applying academic theory to realization of the vision for OPA is beyond the scope of this article. Nevertheless, some practical observations can be made.

After the successful completion of its OPA proof-of-concept project in 2018, ExxonMobil concluded that the major challenge for OPA was supplier and customer business model transformation, not technology factors. With this perspective, let's consider adoption of O-PAS by suppliers, end users, and system integrator companies as a key performance indicator. Seven broad observations of the current state of industry adoption of O-PAS are made in this section of the article.

Observation 1. O-PAS Version 2.1 Final, published on February 6, 2023, is the fifth release of the standard since initial publication of Version 1.0 in January 2019. Anecdotally, several suppliers have stated that O-PAS V2.1 (Preliminary and Final) are sufficiently specific and complete enough to be the basis for product designs [*4*].

Observation 2. OPAF has announced the start-up of formal O-PAS Conformance Certification testing in mid-2023 after an almost two-year "soft opening" with a small group of suppliers who have submitted early versions of O-PAS roadmap products for their own testing and to assist OPAF with checkouts of the verification test cases and tools.

Observation 3. At least nine end-user companies are doing, have done, or have committed plans for OPA prototyping projects of varying degrees of sophistication. Table 3 lists the companies that have publicly announced OPA projects (Yokogawa is the system integrator for four of the projects listed in Table 3).

The largest and most comprehensive project in Table 3 is ExxonMobil's field trial. It is the company's third OPA system-building project. The first two were a laboratory proof-of-concept and a prototype that controlled a hydrocarbon processing pilot plant with 140 I/Os [*17*]. The field trial is on a manufacturing facility in Louisiana with 2,500 I/O and about 100 control loops. The OPA system replaces a DCS and several PLCs. The system is currently in construction and is scheduled to be commissioned in 2023.

Observation 4. To help build the emerging market for OPA, ExxonMobil established an on-going "Collaboration Partnership" among the companies listed in Table 3, as well as several others, to exchange non-competitive information about their OPA projects. Such reference exchanges among the early adopter members of an emerging high-tech market are essential to build critical mass and momentum to "cross the chasm" of market adoption to the early majority population [*18*].

Observation 5. Five of the seven global major distributed control system (DCS) vendors are active contributors to the OPA Forum. These five companies represent 74% ($44.6 billion) of the total worldwide revenue ($59.9 billion) of all seven companies [*19*]. While support for OPA is not prominent in the mainstream marketing collateral from the five active contributors, these companies are publishing information about their activities and plans for OPA [*20–23*].

Many of the OPA fundamental principles and characteristics are

TABLE 2. O-PAS CONFORMANCE REQUIREMENT PROFILES INCLUDED IN CERTIFICATION WAVE 1

Profile	O-PAS Part	Description
DCP-001	Part 7	Distributed Control Node Platform
NET-F-001	Part 4	Single Ethernet to Ethernet
NET-F-002	Part 4	Single Ethernet Peer to Peer
OCF-001	Part 4	OPC UA Client/Server
SEC-F-001	Part 2	IEC 62443-4-2 Cybersecurity
OSM-002	Part 5	Redfish (system management) with Baseboard Management Controller (BMC) chip
OSM-003	Part 5	Redfish without BMC chip

TABLE 3. OPA PROTOTYPING PROJECTS BY END-USER COMPANIES

Company*	Test bed	Prototype	Field trial	Reference
ExxonMobil			✔	*[5]***
BASF		✔		*[6]*
Georgia Pacific		✔		*[7]*
Saudi Aramco	✔			*[8]***
Dow Chemical		✔		*[9]*
Equinor		✔		*[10]***
Shell	✔			*[11]***
Petronas	✔			*[12]***
Reliance Industries	✔			*[13]*

Notes:
*The author is aware of a tenth major end user with a fully funded, not-yet-announced plan for an OPA prototype
**The reference to the speaker and year of announcement at ARC Forum conferences. OPA sessions at ARC Forums are chaired by Harry Forbes, who has been reporting on OPA since its beginning (14). If the reader is unable to access the referenced presentation or video, synopses can be found in Ref. 7, 15 and 16.

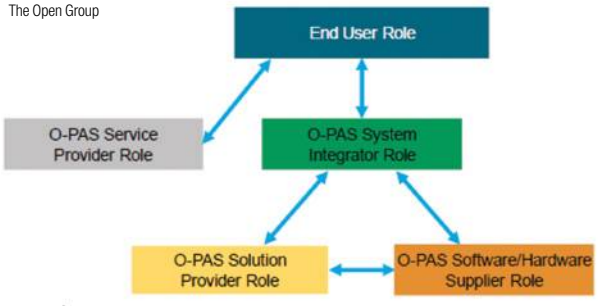

FIGURE 2. Stakeholder roles in the OPA business ecosystem are diagramed here

being incorporated in products of major DCS vendors [*24*]. Examples of these are the following:

- Flatter, software-based architecture that democratizes data
- Avoid building other vertical silos of data for reliability or quality (non-operations) applications
- Non-operations applications currently in OT systems that could move to the cloud
- New generation of edge technologies — Linux, hyperconverged infrastructure, other new IT technologies — could be deployed in more critical automation functions
- Zero-trust security — does not depend on the layered protections, grants access on an as-needed basis — designed into the architecture

In the interest of fairness and fullness of discourse, it is worth commenting on two critiques of OPA, as follows:

- Standards give lowest-common-denominator functionality, limits innovation
- A unified software ecosystem that provides much more ease of use and provides for usability of data

To the first critique, it is essential to note that O-PAS specifies *interfaces* among modular software and hardware components, *not the functional capabilities* of the modules. Suppliers can innovate. Suppliers can protect their intellectual property.

On the other hand, this author does share the concern voiced in the second critique. There are two lines of development in OPAF to cite regarding mitigation of the risks of complexity. First, the OPA Forum has done and is doing extensive work to apply technologies and standards that are well developed in Information Technology (IT) — particularly for enterprise systems and cloud computing — for managing

FIGURE 3. These COPA QuickStart hardware components are available now

TABLE 4. COMPANIES IN THE COALITION FOR OPEN PROCESS AUTOMATION

Company	Company
ASRock Industrial	Nova SMAR
CODESYS	Phoenix Contact
Collaborative Systems Integration	Quest Global
CPLANE.ai	Stahl
Enterprise Transformation Partners	Supermicro
Inductive Automation	Wood
Intel	Yokogawa

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TABLE 5. COPA QUICKSTART SOFTWARE COMPONENTS

Supplier	Software Component
Inductive Automation	Historian
Inductive Automation	HMI & Alarms
CPLANE.ai	Systems Management
Canonical & Intel	Viruualization & OS
CODESYS	IDE
CPLANE.ai & Intel	Orchestration
Canonical & CPLANE.ai	Sofware services
CSI & Yokogawa	Model Predictive Control
CODESYS, SMAR & CSI	61131 Regulatory Control
ASRock, VECOW, Supermicro	Redfish
Pheonix Contact & Stahl	OPC UA & Redfish
Pheonix Contact & Stahl	4-20 mA <-> OPC UA
VP Process & CSI	Simulation

and orchestrating software intensive systems-of-systems. O-PAS Part 5 specifies standards for computing system management. Being drafted now for the next O-PAS release is Part 9 that is applying another well-established IT standard for managing software complexity that, to this author's knowledge, is significantly more sophisticated and powerful than anything that has been used to date in OT service.

Second, much of the work being done by the systems integrators and suppliers involved in the prototyping projects listed in Table 3 is addressing ease-of-use and cohesiveness of the software environment. This work is likely to improve interfaces of the modular components and result in systems-integration methods and licensable technologies to mitigate the risks of software complexity.

Observation 6. New entrants to the industrial control system business ecosystem are emerging and earning contracts from end-user companies for OPA products, systems and services. One such new entrant, a group of companies called the Coalition for Open Process Automation, is discussed in the next section of this article.

Observation 7. End-user companies are starting to issue Requests for Proposals (RFP) that require respondents to address current capability and plans to supply O-PAS-conformant products or O-PAS-based systems. The author's company has received three such RFPs in the past 10 months.

Example: COPA QuickStart

"If we could buy an OPA system we would," and "how do we get started with OPA?" are paraphrases of comments and questions that the author has heard from end-user companies over the last couple of years. To address these questions, CPLANE.ai and Collaborative Systems Integration organized a group of companies, named the Coalition for Open Process Automation (COPA), to bring to market an OPA entry-point that is significantly less expensive and resource-intensive than the test-bed projects listed Table 3.

The fourteen companies in the Coalition for Open Process Automation are listed in Table 4. All are members of the OPA Forum. Important to note: COPA is independent of the non-commercial OPA Forum. Collectively, the COPA companies span all the OPA business ecosystem stakeholder roles except for the end user.

In November 2021, the coalition launched COPA QuickStart, a small-scale functional control system and structured training program. The COPA QuickStart system consists of one portable cabinet shown with the hardware component breakdown shown in Figure 3. The COPA QuickStart software components are listed in Table 5.

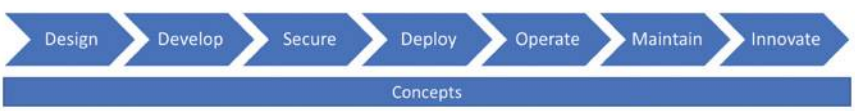

FIGURE 4. Shown here is an outline of the COPA QuickStart training curriculum

The structured training program curriculum starts with an introduction and demonstration that is targeted for a broad audience (engineering and management), and then moves on to a course of lectures and hands-on labs teaching content — particularly what's different with OPA — that spans the lifecycle of a control system.

In teaching the course, we learned that it is difficult for attendees to understand Open Process Automation from a linear reading of the O-PAS standards documents. Therefore, we increased the emphasis on telling the OPA story from a narrative based on the OPA quality attributes documented in the *OPA Business Guide* that focuses on the "what problems are you solving" questions. Furthermore, we learned that each cohort of attendees has differing degrees of interest in hands-on labs. Accordingly, we adapt the course as we teach it to accommodate the attendees' needs.

Now, 18 months after the launch of QuickStart, the COPA companies have adapted and expanded the original QuickStart concept into the following three offerings based on feedback from the end-user community:

- Original QuickStart system and training
- Training-only
- Projects for small-scale, on-production O-PAS based systems

Concluding remarks

The fifth release of the O-PAS standard, Version 2.1 Final, was published in February 2023. Multiple companies have expressed opinions that O-PAS V2.1 Final is now sufficiently specific and complete enough to be the basis for product designs.

The OPA business ecosystem is coalescing and strengthening such that multiple, simultaneous OPA prototyping projects are underway in North America, Europe and Asia Pacific. At least nine end-user companies have done or are doing OPA prototyping projects.

The first wave of independent certification of products for conformance to the O-PAS standard is starting up now and is expected to be operational in mid-2023.

Seven indicators of industry adop-

tion of OPA are reported in this article. Among the indicators is the appearance of requirements for O-PAS conformance in Requests for Proposals from end-user companies.

Both incumbent DCS vendors and new entrant companies are stepping up to perform the system-integrator role in the emerging OPA business ecosystem. ■

Edited by Gerald Ondrey

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For more on this topic, see "Open Process Automation is Gaining Sustainable Momentum," by Kevin Finan, *Chem. Eng.*, pp. 39–41, January 2023, which is available at www.chemengonline.com.

Owning Your Career: Transitioning From a Technical Role

Making the decision to change career paths from a technical role to a more managerial one can be difficult. Here are some considerations to take into account

Garrett Forsythe
JGF Performance Consulting

As a technically trained chemical engineer, career opportunities are very broad with respect to the type of work, size of company and location. While there is certainly no "typical" career, there is often a general career path that starts you off in a primarily technical role. As a reader of this publication, you take your technical professional development seriously. In addition, in those first years, you are measured as an individual contributor, or part of a team, where your contributions are evaluated. Sometime in the first 2–6 years of employment, there can be a point where an opportunity to move to a management, leadership or business-related opportunity arises (Figure 1). How does one determine if this career opportunity is worth pursuing? What if success in the new role is much more focused on managing others and a more complex scope of work? What if you would like to stay on a technical career path? Is your temperament and personality suited to the new opportunity? These are challenging questions.

Should I pursue a new role?

Your definition of success is something only you can determine. Choose to pursue a career that fits your goals, work-life balance and preferences. Some of the most content engineers I have known have stayed in a technical role for most or all of their careers. I also know engineers who now are chief executive officers or chief operating officers. Some, like me, have led chemical businesses, sales and marketing teams, and global supply chains. Others pursued careers outside of the chemical process industries (CPI) in medical, sales, legal, financial and business roles. How do you determine what path is right for you? What is your right balance of individual contribution, team contribution, or leading and managing others?

In a previous article [*1*], I reviewed the importance of having a personal development strategy that helps set up success, regardless of your industry and specific job role. An important consideration is the "soft skills" needed to succeed — including things like understanding personalities, communication effectiveness, leadership skills, understanding and practicing emotional intelligence and more. Working effectively with others is critical if you are an individual contributor and if you are leading a complex operation as a site manager. While I presume that your technical competence is strong, and that you are doing well in your current assignment, you still will want to expand your capabilities and skills to prepare yourself for roles of greater breadth and responsibility, regardless of whether it is along a mostly technical career path or not.

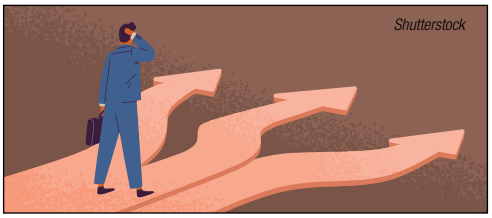


FIGURE 1. An engineer's career path can lead to technical, management, business and other leadership roles

Why consider a change?

Assuming you are successful in your current role, and that it has primarily been a technical one, you could be asking the question "Why would I want to make a change from what I am currently doing?" There could be multiple reasons under consideration, including the following:

- Am I unhappy or discontent in my current job and ready for a change? Or am I happy and content but still ready for something different?
- Am I looking for a new challenge with more responsibility and broader scope?
- Do I want to move into an expanded role where I will then have people reporting to me?
- Am I being offered a new opportunity by my leadership team that looks interesting?
- Is it time to consider a new working group, company or location?

Typically, each job scope has a ratio of how much success is based on your individual technical contribution and how much is based on your group contribution and your leadership and management capabilities. Fortunately, as an engineer, there are many options for individual contributions and for team contributions.

Moving into a new role where you have people reporting to you brings a whole new set of dynamics to the picture. In engineering curricula, management and leadership competencies are rarely discussed. Soft skills are often left out of any formal training, and you need to develop them somewhat on your own.

Managing versus leading

Making the shift to your first management role is a big decision. There are many references that talk about the differences and similarities between managing and leading individuals and teams. Through my experiences, I often have found that there is much overlap and that even in technically focused roles, there are needed skills related to both. If you are moving from an "individual contributor" role to a "supervisory role" (where you have responsibility and accountability for direct reports), it is even more important to understand the differences between managing and leading. Both are crucial to be successful. Typically, when moving from a technical role into your first managing or leading role, you will need to improve your

TABLE 1. SKILLS NEEDED FOR MANAGING AND LEADING

Managing Skills	Leading Skills
Developing the work and execution plan	Developing the vision and strategy
Planning, scheduling and assigning work	Setting goals and key metrics
Delegating work to the right individuals and teams	Ensuring the work team is resourced and capable
Coordinating and optimizing (efficiency)	Working on the right things (effectiveness)
Focusing on structure and systems	Focusing on people and positive change
Maintaining safety, operations and cost control	Improving and innovating
Placing most attention on near-term priorities	Placing most attention on longer-term direction

skillset in both arenas. Table 1 shows some of the key skills for each.

This certainly is not an exhaustive list, but it is intended to show the skillsets needed for roles that are primarily managing or primarily leading. One needs to consider both columns when moving to a new position and work to understand what aspects of each will be key for your success.

My experience is similar with many other engineers I know. Typically, an opportunity transitioning from an individual contributor role leads to one leading people, but with a smaller group and scope to start. Depending on performance after that, roles with increased responsibility and job breadth develop. When you are an individual contributor, your personal efforts, technical proposals and work is mostly controlled by you. When you start leading a team, you are responsible for the performance and contribution of the entire group. Influence and communication skills become even more important and visible. Working with individuals with a wider range of personalities and perspectives to achieve common goals becomes your responsibility (and challenge). Some of your team may be more relationship-oriented, others may be more task-focused. Some will be introverted, others extraverted. A broader set of skills is going to be needed to adapt and thrive. Some will be more big picture oriented, others will dive into the details. You will need to learn the challenging lessons of how to treat people as individuals, while being fair with equal treatment in many aspects of managing and leading. New skills, like how to have a difficult conversation, become even more critical.

There are a number of great leadership and management resources to help you consider and build new skills, mindsets and behaviors. Some that I have found personally helpful, and have also been beneficial to those I coach, are listed in the box on p.44.

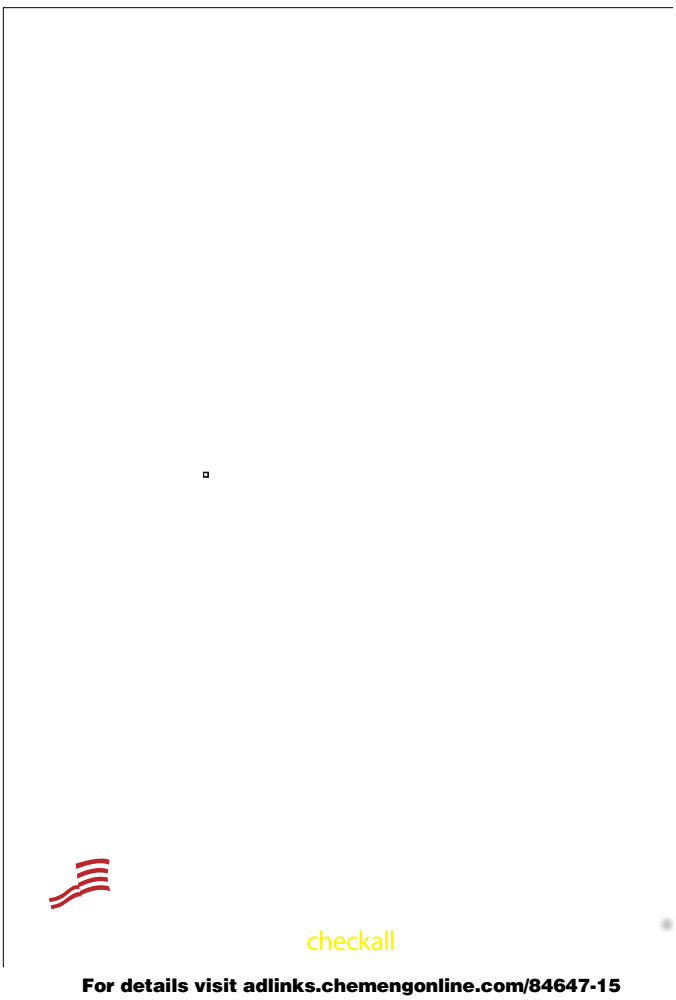
These are just a few of the impactful books that are available. Additional resources that I have used while coaching and mentoring individuals in their career growth include works by experts such as Daniel Pink, Daniel Goleman, Stephen Covey, Ken Blanchard and Patrick Lencioni. Numerous podcasts by these people and others that cover leadership, management, team development and more are great for listening to while exercising, driving or relaxing. There is much debate on what makes a successful leader and manager. You will need to develop your own style and approach based on your job scope, organizational culture and your personality. Your leadership team should certainly be supportive if this is your first supervisory role. Ideally, you can also find a mentor or coach who can help you — ideally someone not directly in your reporting line. One foundation that never changes is that you will want to work to build genuine trust with your team (your supervisor, peers and direct reports). This has always been a critical success factor that I have seen over my career and multiple roles. Integrity matters most.

Transitioning successfully

Taking a purposeful approach to your transition from a primarily technical role to a different role is important to help you get organized and prepared. When I have worked with engineers considering a move from a technical role to a new opportunity, there is often a combination of emotions and questions. Some of these are typically the following:

- What will I need to learn and know to be successful?
- How do I best get off to an effective start?
- Will I miss my technical challenges and comfort zone?
- What if I do not like the new role — can I return to a technical role or have I "burned a bridge"?
- What effect will it have on my current work-life balance?
- How will I like managing and leading others as part of a team?

These are all very good questions



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SUGGESTED READING LIST FOR BUILDING LEADERSHIP AND MANAGEMENT SKILLS

"The Leadership Challenge" by James Kouzes and Barry Posner, John Wiley & Sons, 2017

"The Making of a Manager" by Julie Zhou, Penguin Publishing Group, 2019

"Crucial Conversations" by Patterson, Grenny, McMillan and Switzler, McGraw Hill LLC, 2021

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"The First Time Manager" by Belker, McCormick and Topchik, HarperCollins Leadership, 2021

"Emotional Intelligence 2.0" by Travis Bradberry and Jean Greaves, TalentSmart, 2009

"Strengthsfinder 2.0" by Tom Rath, Gallup Press, 2007

"The First 90 Days" by Michael Watkins, Harvard Business Review Press, 2023

"On Managing Yourself" by Harvard Business Review, Drucker, Christensen and Goleman, Harvard Business Review Press, 2011

"Leadership 2.0" by Travis Bradberry and Jean Greaves, TalentSmart, 2012

"Developing the Leader Within You 2.0" by John C. Maxwell, HarperCollins Leadership, 2019

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to consider.

So, what if you decide to take a new opportunity and now are leading a team for the first time, working in a business versus operational setting, or changing to a new company or work team? You certainly want to get off to an effective start. Your first months in a new role will make a statement to those around you on your capabilities, contributions and potential.

One resource that I have found very helpful in these situations is the book "The First 90 Days" by Michael Watkins. This book offers many proven strategies and frameworks to utilize when designing your transition plan and build foundations for a positive change to new work, new relationships and new needed skills to succeed. Watkins surveyed more than 1,300 senior human-resource leaders and about 90% of them agreed that "transitions into new roles are the most challenging times in the professional lives of leaders." They also overwhelmingly agreed that "success or failure during the first few months is a strong predictor of overall success or failure in the job"[*2*].

One of the first tools discussed in his book is a transition risk assessment. This can be used even as you are considering a new role or even the change from your current role to a new role. Questions help you assess both the types of transition and your assessment of how difficult each type would likely be for you. Would you be in the same company or group or moving to a new company or location? Is it a cross-functional leadership role? Is the new role newly created or existing and clear?

Once you decide upon and make the move to the new role, your challenge is to make the transition as smooth as possible. As a technical professional, a first temptation is to realize that your approach to the job will need to adapt to the new priorities and critical operational tasks (COTs). If you now have direct reports, you will want to successfully build those relationships.

Understanding your strengths (and derailers)

Taking a purposeful approach to understanding your strengths and weaker areas is important. You can't be everything to everyone and you need to play to your strengths, find others around you (and on your team) that cover your weaker areas, and know your potential derailers. Working on the potential derailers is often more critical than building up your weaker areas. Key associates and friends can help you in this, along with the reference "Strengthsfinder 2.0" mentioned in the box.

One of the mentors in my career reminded me that "If you always do what you have always done, you will only get what you already have got." He also reminded me that you can't stand still in your career development — you are either moving forward or moving backward. As I mentioned in my prior article [*1*], there are many opportunities for self development — having mentors, listening to podcasts, reading books and magazines, web references — the list is endless.

Staying in a technical career

You may have read this and concluded that you want to stay primarily on the technical career path. Good for you. As I mentioned earlier, some of the happiest and content chemical engineers I know have stayed on a primarily technical path. Some have led small task teams, others have been individual contributors. Some have successfully switched back and forth between leadership and individual contribution roles. Only you can decide what is best for you. If you do choose the technical path, be sure you are in an environment or organizational culture where this is rewarded and appreciated. This is not always the case, and sometimes that has led my peers to seek an opportunity elsewhere where their contributions are valued more.

Moving forward

Continued development is important regardless of what career path you choose. Certain skills become more important and visible as you increase job scope and begin to lead individuals and teams. Find coaches and mentors who can help you develop new skills and approaches. Sometimes new role or job opportunities arise where you are currently, while other times you need to actively pursue them. In the end, only you can evaluate what type of role is your sweet spot to succeed and be professionally satisfied. ■

Edited by Dorothy Lozowski

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1. Forsythe, G., Owning Your Career: Taking a Hard Look at 'Soft Skills', *Chem. Eng.*, pp. 41–44, July 2020.
2. Watkins, M., "The First 90 Days," Harvard Business Review Press, p. 1, 2013.

Author

Garrett Forsythe is an engineering consultant and executive coach specializing in operational excellence and leadership development. (forsytheopex@gmail.com, Phone: 610-304-0630). With DuPont, he had high-hazard operation leadership experience, business and sales leadership roles, and helped design and execute major enterprise-wide continuous improvement programs inside DuPont and with external clients. He now operates JGF Performance Consulting, LLC and focuses on coaching early and mid-career individuals. His 40+ years of operational, supply chain, business, and consulting experience has primarily been in the chemical and mining industries. He holds a B.S.Ch.E. from the University of Delaware.

Cutting Cost and Waste with Rinsewater Recycling

Onsite recovery conserves one of the most precious resources — water. A well-engineered, closed-loop recycling system can pay dividends in avoided costs to treat and discharge wastewater

Rick Hines
GF Piping Systems

In Southern California, few businesses dispute the need for water conservation. In a naturally arid region that is also a center of industry, it is clear that every drop of water used in industrial processes comes at a cost — to the environment, as well as to the bottom line. In short, all incentives align in favor of responsible reuse. In light of these facts, closed-loop water-recycling systems can offer a cost-effective alternative to one-time water use for industrial processes. Such systems can be designed for specific process needs, and in many cases, can provide 95% or greater water recovery.

Designing the recycling system

In 2017, a manufacturer in the aerospace sector sought a way to reduce costs and wastewater at a site located in Southern California. To rinse metal parts as they are cleaned, etched and electrolytically plated with specialized metal finishes, the company's operations require a high volume of deionized (DI) water. They therefore also produce a high volume of metals-bearing wastewater. A majority of this volume consists of rinses that can be closed-loop recycled by ion exchange in a cost-effective manner. The remainder requires specialized treatment to remove cyanide and heavy metals before discharge to sewer.

During its decades in operation before the installation of a new rinsewater recycling system, the business sourced all its water from the Metropolitan Water District of Southern California, using portable exchange deionization (PEDI) vessels to produce a limited volume of DI water, at a cost of approximately $70–80 per 1,000 gal. Given this high cost, the manufacturer only used DI water for critical process rinses. And at the end of the manufacturing process, 100% of the wastewater was discharged to the Orange County Sanitation District, after expensive chemical treatment to comply with regulatory discharge limits.

FIGURE 1. Water Innovations' HFX75d recycling system, supported by process-automation technologies from GF Piping Systems, reduced wastewater management costs for an aerospace manufacturer by 80%

When the company decided to enlarge its metal-plating operation, they worked with Water Innovations, Inc. (San Diego, Calif.; www.waterinnovations.net) to develop an onsite system for rinsewater recycling. Utilizing a wide array of measurement and control instruments, sensors and valves supplied by GF Piping Systems (Irvine, Calif.; www.gfps.com), the HFX75d system engineered by Water Innovations (Figure 1) selectively recycles wastewater to maximize closed-loop recovery of usable water.

As described by Water Innovations managing partner Steven Ward: "This recycling is achieved through the use of three different resin systems: one that recycles up to 75 gal/min of select compatible rinses; one for oxidation and removal of cyanide from precious-metal plating rinses; and a polishing system with a series of specialized PEDI vessels to remove residual regulated heavy metals and cyanide from the remaining effluent prior to discharge to sewer." Water Innovations also developed a proprietary bentonite reactant-treatment system that would allow onsite treatment of a high-volume, oily wastewater stream. In total, the volume of wastewater requiring chemical treatment before discharge has been reduced by over 60%.

Water recycling gets results

With the new system providing an abundant supply of DI water (and with the cost per gallon reduced by about 70%), the aerospace company has been able to expand the use of the system to a wider range of rinse processes, with a positive impact on product quality. Meanwhile, compared with the process of purchasing water, using it once, waste-treating and discharging to sewer, the business' investment in closed-loop rinsewater recycling with segregated waste treatment has brought down their overall wastewater-management cost by approximately 80%, the company says. The recycling process produces DI water at a cost of $5–6 per 1,000 gal — a significant improvement over their previous cost of $70–80 for PEDI purification of potable water. Given that disposal expenditures were greatly reduced as well, the company achieved return on its Water Innovations investment in approximately two years. As of November 2022, assuming HFX75d operation at 75 gal/min, for around 100 h per week, since startup in March 2017, this aerospace supplier had recycled (and therefore avoided discharging to the publicly owned treatment works) an estimated 120 million gal of water.

For nearly two decades, Water Innovations' water recycling and

FIGURE 2. Specification of the proper components — from pH sensors to pressure-reducing valves — was critical to ensuring the success of the water-recycling system

wastewater treatment systems have been engineered and manufactured exclusively with GF Piping Systems' components (Figure 2). Critical GF components provided for the HFX75d system include: 2850 conductivity sensors, 2750 pH sensors, and 2580 flow sensors; Type 523 metering valves, which regulate the HFX75d regeneration cycles; Type 233, 285 and 288 air-actuated valves, which regulate the duplex systems that alternate between service and regeneration cycles; 582 pressure-reducing valves; 586 pressure-retaining valves; and 514 diaphragm valves, which autonomously maintain constant pressure for the blending and injection of the resin-regeneration chemistry.

As described by Ward, the results of this approach are a "win-win-win" for Water Innovations, their suppliers and their customers — as well as for a world where water scarcity is a growing concern. To operate its Orange County facility, the aerospace company needed high-quality water for rinsing and a reliable process for regulatory compliance, both at costs it could afford. The HFX75d recycling system from Water Innovations makes it possible for the business to achieve both goals. With the company's need to draw on the finite public water supply drastically reduced, Orange County officials have reason to smile as well. Ward commented proudly: "Having been recycling water for 20 years, or literally hundreds of millions of gallons of water that have been reused by our customers — I think that's really the epitome of sustainability." For a business squarely founded on "leaving things cleaner than you found them," this claim seems well justified. ■

Edited by Mary Page Bailey

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Rick Hines is the director of automation for GF Piping Systems' U.S. Center of Excellence (9271 Jeronimo Rd., Irvine, CA 92618; Email: rick.hines@georgfischer.com). With over four decades of experience in the field of fluid handling, Hines is active in the effort to provide safe, clean and reliable water supplies to communities.

Gulf Coast
special advertising section

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Access Intelligence

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Boiler Solutions for the Petrochemical and Processing Industries

HRST specializes in technical services for Waste Heat Boilers, Process Gas Boilers, OTSGs, HRSGs and Package Boilers for the power industries.

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HRST takes experience from inspections and problem analysis to develop innovative design solutions. These solutions often become products for clients, including pressure parts, burner viewports, piping penetration seals, complete liner systems and system re-designs. HRST also provides technical field services to support projects. HRST expert guidance from Technical Field Services can offer turnkey solutions, repairs, vendor surveillance, technical advisors with installation, and quality assurance. HRST provides training on-site or off, with HRSG Academy (twice per year), on-site training, and on-demand remote training.

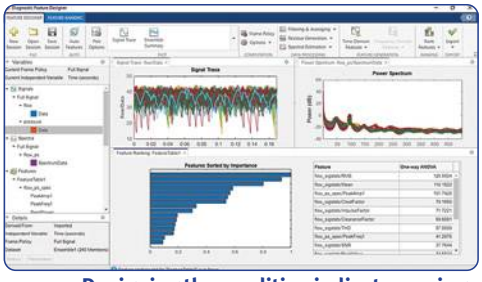
Occasionally clients have an emergency need for HRST's engineering or technical advisory services due to unforeseen failures leading to forced outages. HRST deploys an expert on-site to identify the problem, provide a solution, and oversee repairs, ensuring that the facility is back up and running as soon as possible.

Globally, HRST engineers, technicians, designers, field advisors, and project managers are committed to helping clients avoid and solve costly boiler problems. HRST is represented throughout the United States with regional offices in California, Colorado, Florida, Maine, Maryland, Minnesota, and Texas. HRST has international offices in Vietnam and Mexico and is a registered business entity in Australia.

www.hrstinc.com/process-boilers

Predictive Maintenance Makes Refineries Safer

Ensure the mechanical integrity of critical process equipment with cost-effective predictive maintenance programs



Designing the condition indicators using Predictive Maintenance Toolbox

Through OSHA-compliant process safety management standards, petroleum companies aim to prevent the release of chemicals that may ignite, cause fires and explosions, or have toxic impacts. Mechanical integrity is chief among process safety management elements because it covers the maintenance of process equipment, including pressure vessels, piping systems, valves, pumps, and more. The key to maintaining mechanical integrity within a large chemical plant is to implement a successful predictive maintenance program.

Predictive maintenance enables process engineers to monitor the health of their process equipment, estimate machines' remaining useful life, and pinpoint the root causes of problems before critical failure. Unlike preventive maintenance—which relies heavily on maintenance schedules and frequently takes equipment with usable life offline—predictive maintenance is more cost-effective because it helps engineers find the optimum time for maintenance.

Many engineers in the refining industry use MATLAB® and Simulink® products for predictive maintenance algorithm development and deployment steps.

To develop a predictive maintenance algorithm, chemical engineers must first preprocess raw equipment data to extract condition indicators and distinguish between healthy and faulty conditions. Preprocessing is often a time-consuming step. With MATLAB and Predictive Maintenance Toolbox™, engineers can design condition indicators using signal-based or model-based approaches. Using condition indicators, machine learning models can be trained to detect anomalies, classify different types of faults, and predict the transition from healthy state to failure. Many built-in functions are available to simplify basic preprocessing, filtering, and preprocessing in the time, frequency, and time-frequency domains.

Another predictive maintenance challenge is aligning hardware data with different sampling rates—specifically, accounting for missing data, outliers, and insufficient data to cover various operating conditions. Engineers can generate synthetic data for various operating conditions through parameter estimation and process equipment modeling in Simulink to build robust predictive maintenance models without having a large data set featuring healthy and faulty operations.

MATLAB and Simulink help chemical industry engineers create and scale effective predictive maintenance programs that ensure the mechanical integrity of their equipment and create safer processes. Additionally, these predictive maintenance models can easily be deployed to hardware or IT/OT systems to share the results with plant operators.

www.mathworks.com/solutions/predictive-maintenance

Paratherm Heat Transfer Fluids are used in chemical manufacturing processes delivering uniform heating and cooling

Paratherm – Heat Transfer Fluids, a Division of The Lubrizol Corporation has been in business for over 35 years. The premier provider of engineered heat transfer fluids in the industry, they offer a range of products and services. **Paratherm** offers a wide range of heat transfer fluids (currently 8 fluids and 3 cleaners) covering temperatures from -137°F to +650°F. Their fluids are designed to handle conditions from maintaining high temperatures or extreme process cooling. Their expert knowledge serves the wide range of applications in the chemical processing industries.

Paratherm heat transfer fluids are used in numerous chemical manufacturing processes requiring unform precision heating and cooling. Equipment applications include heating and cooling of chemical reactors, reboilers, distillation towers, jacketed vessels, platens/presses, autoclaves etc.

They proudly offer an extensive fluid analysis program. Paratherm performs real time testing with results in our state-of-the-art, on-site laboratory. Each report gives an in-depth analysis of the current condition of your fluid. Their technical specialists perform a combination of laboratory testing to provide an effective analysis which includes recommendations for continued maintenance and how to extend the life of your fluid. They are also a resource for all your training, troubleshooting and technical questions. Paratherm houses an extensive resource library on their website full of safety, maintenance, and technical information.

Paratherm™
HEAT TRANSFER FLUIDS
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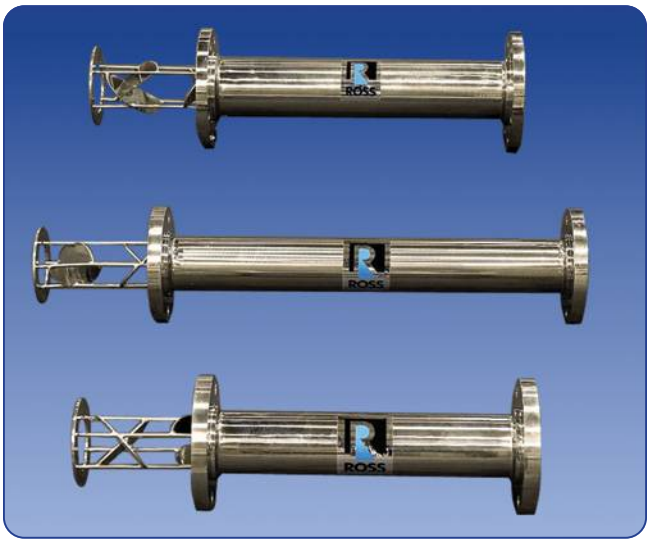
Paratherm is able to provide a vast network of distributors and warehousing locations throughout North America and globally which enables them to offer regional service and quick delivery. Paratherm is here to help and provide 24/7 emergency response. At Paratherm, they provide superior service for all your fluid related needs.

www.paratherm.com/heat-transfer-fluids

A classic mixing tool for the petroleum industry

Ross LPD Static Mixers are rugged, reliable devices that combine excellent inline mixing with minimal pressure loss

Ross Low Pressure Drop (LPD) Static Mixers are used throughout the oil and gas industry for turbulent-flow mixing applications.



Shown are removable LPD mixing elements supplied with retainer ring and flanged housing.

These heavy-duty low-maintenance devices serve in continuous operations where high performance and accuracy are required, such as on-line water determination of crude oil; dosing of various additives into gasoline; blending different kinds of fuel oils; gas-gas blending; and pipeline reactions, among others.

Static mixers have no moving parts and the energy for mixing is available in the form of pressure. Pressure loss – a natural consequence of static mixing – sometimes becomes the deciding factor in mixer selection. The LPD Static Mixer remains a classic choice for many inline blending requirements due to its simple and durable design capable of uniform mixing with little pressure loss. The mixer elements consist of semi-elliptical plates carefully positioned in series to split and rotate the product 90 deg. in alternating clockwise and counterclockwise directions.

LPD mixers in diameters from 1 in. through 2.5 in. are welded to a central rod, while larger elements are welded to four outside support rods for maximum rigidity and stability. Units as large as 48 in. diameter can be supplied as stand-alone mixer elements or as modules complete with a mixer housing and injection ports.

Established in 1842, Ross is one of the oldest and largest mixing equipment companies in the world. Ross mixing, blending, drying and dispersion equipment is used throughout many industries in the manufacture of foods, adhesives, electronics, coatings, cosmetics, pharmaceuticals, plastics and composites.

www.staticmixers.com

Sulzer Chemtech successfully starts up world's largest pygas-to-styrene extraction unit

Sulzer Chemtech (GTC Technology) has completed the start-up of the world's largest facility for styrene extraction from pyrolysis gasoline (pygas) derived from naphtha cracking. Located in Zhejiang Petroleum & Chemical Co., Ltd.'s (ZPC) integrated refining and petrochemical complex in Zhoushan, China, the unit uses **Sulzer Chemtech**'s proprietary GT-Styrene® licensed technology to produce 100'000 tonnes of styrene per year.

The new facility upgrades pygas, a by-product obtained from three steam crackers in Zhoushan's plant, by extracting valuable styrene for use in the petrochemical industry. The process flexibility offered by GT-Styrene is enabling the plant to obtain high-quality ASTM 2827 grade styrene from three different units within a single train. This will help ZPC increase the overall profitability of its integrated refining and petrochemical complex.

ZPC selected Sulzer Chemtech due to its prior extensive experience in styrene extraction and positive outcome of previous collaborations. Sulzer Chemtech supported all stages of the project, from delivering a licensed Basic Engineering Package, to supplying proprietary equipment and chemicals, providing support during the detailed engineering phase, and successfully completing commissioning and startup of the unit.

www.sulzer.com

End-to-End Turnaround Planning Plus Global Service Approach Reduces Costs and Outages

What should you expect from a turnaround or retrofit project? A provider strategically positioned for fast customer response anywhere in the world, with the field experience and technical expertise to get the job done right. **Zeeco**'s turnaround services mean you have a single point of on-site contact for all your fired equipment during a planned shutdown. If you need to retrofit burners or reduce emissions, trust Zeeco for an end-to-end gas or hydrogen-firing burner retrofit solution.

Our streamlined system ensures customers all planning and project execution is managed quickly and efficiently through a single point of contact. From before your system is engineered to years after its commissioning, Zeeco's Global Field Services group backs you up with the technical services and field expertise to optimize equipment performance and enhance daily operation. Some of the services we offer include:

- Start-up & Commissioning
- Training
- Maintenance Agreements

- Combustion and Equipment Surveys
- Unmanned Aerial (Drone) Inspection
- Global Bridge Augmented Reality Field Services Kit
- Turnkey Power Solutions and Services
- Flare Tip Replacements
- Vapor Control Service and Maintenance

Zeeco can supply parts for all Original Equipment Manufacturers' (OEM) combustion equipment, with competitive pricing and rapid delivery. Our engineers are industry experts with a customer-first mentality. With Zeeco combustion specialists on-site, rest assured that your equipment will be installed and commissioned properly – avoiding costly mistakes that affect future performance.

Whether you face a full-scale emergency or a simple maintenance need, renting the right combustion equipment can be frustrating. ZEECO combustion rentals span the scope and capacity to keep any facility's essential operations online during both planned and emergency flare outages. Our rental flare systems are supported entirely by ZEECO turnkey combustion services and can keep specific processes online – eliminating the need to fully de-inventory plants and shortening turnarounds. ZEECO rental equipment includes flare systems, flare monitoring and control systems, thermal oxidizers, and vapor combustors. Our aftermarket team delivers the same attention to detail, engineered expertise, and on-time, on-spec performance – whether you have ZEECO equipment or not. From turnarounds through retrofits and rental equipment, Zeeco's project management and engineering expertise consistently delivers the outcomes that our customers demand. For more information, contact sales@zeeco.com or call 918 258 8551.

www.zeeco.com

Finding the optimal level measurement solution

VEGA's latest flagship radar sensor makes it easier than ever to increase safety and efficiency in refining and petrochemical operations.

For refining and petrochemical operations, safety is of paramount concern. Inventory events like overfills can not only negatively impact business, but also deal catastrophic environmental damage. That's why it's critical that facilities in these industries utilize a reliable level measurement solution. With the right sensors for the job, operations become more automated and efficient, leaving personnel free to focus on more pressing matters across their facility.

Unfortunately, not all refining and petrochemical operations are using the best instrumentation for their particular application needs. And it isn't hard to see why: shopping for measurement sensors traditionally involves navigating through confusing product names, model numbers, frequency ranges, and other cryptic points of data. Simply purchasing a sensor that fits the process can seem like a win all in itself, but that doesn't always mean it's the optimal configuration.

The process measurement experts at **VEGA** understand the importance of simplicity. It is one of the core values that guides their product design process. VEGA sensors are made to be easy to set up, commission, and use, with simple and intuitive operation features. But VEGA identified another area in which simplicity was sorely needed: the purchasing process itself. That's what lead to the creation of the company's latest radar level sensor, VEGAPULS 6X.

VEGAPULS 6X is one radar sensor for any level measurement application, liquids or bulk solids. By specifying their application needs via VEGA's online configurator, customers will receive the level sensor that's right for them. That means critical features like PTFE antenna covers for chemical resistance in storage and buffer tank applications, SIL-certified configurations for safety instrumented systems, and more are all just a few clicks away. And just like VEGA's other instrumentation, it's easy to set up and use, with optional Bluetooth connectivity enabling wireless operation via smartphone or tablet.

Of course, simplicity means nothing if a sensor isn't reliable. VEGAPULS 6X gives refining and petrochemical operations a measurement solution they can depend on, delivering precise measurements under even adverse conditions like high temperature, dust, or extreme pressure. And VEGAPULS 6X meets the highest standards mandated by IEC 62443; when combined with SIL certification, that makes this a sensor that's safe from the inside and out.

Safety, reliability, and precision are easy to find all in one place: VEGAPULS 6X.

www.VEGA.com

Eductor system improves Mixing/Blending processes.

There are many processes in chemical production and processing that require the addition and then mixing of solids into a liquid. The most traditional way of doing this is to mechanically convey and meter the dry materials directly into a vessel and then mechanically agitate and mix the contents of the vessel. **Hapman**'s Solidquid is often a significantly more efficient, lower maintenance and typically lower cost option in many applications.

The heart of the Hapman Solidquid is an eductor, which is a specially designed constricting orifice with no moving parts. The Solidquid uses the Venturi Effect which occurs when a gas or liquid at high pressure and low-velocity moves through a specially designed transition becoming a low pressure high-velocity stream. A vacuum is created at the high to low pressure transition point where gases, liquids or solids can be introduced for transport. Hapman always uses an integrated washdown bowl at the solids feed point that significantly improves suction capacity and reduces the amount of air entrainment. The washdown bowl also ensures solids do not cake and build up at the inlet point.

Eductors still utilize blowers, fans and pumps to move the fluid, but they dramatically simplify systems where material is already being transferred by creating a suction inlet point for introduction of additional materials. Requiring only a motive or driving fluid to operate, they have no moving parts that results in low ongoing maintenance or troubleshooting. They can be used to capture and convey gases, liquids or solids. Hapman utilizes them specifically for solids additions to liquids up to 20% solution, but 10% solids solution is more typical.

Eductors are used in industries such as wastewater treatment,

chemical processing and food production. They prevent product clumping and contamination, and they improve mixing speed and efficiency. Eductor systems also avoid problems like plugged filters and dusting in pneumatic conveying. Hapman has discovered they are very effective for handling hazardous dusts by introducing them to a downstream fluid for conveyance as early as possible.

Hapman has found eductors are still underutilized in ideal applications like mixing and blending chemicals or specialty beverage products.

The Solidquid integrates well with other Hapman equipment including Bulk Bag Unloaders, Gravimetric Feeders, and high accuracy feeding controls to ensure the perfect mixture every time. Most importantly, installation is simple and they provide long term consistent performance.

www.hapman.com

Economic Indicators

2021 2022 2023

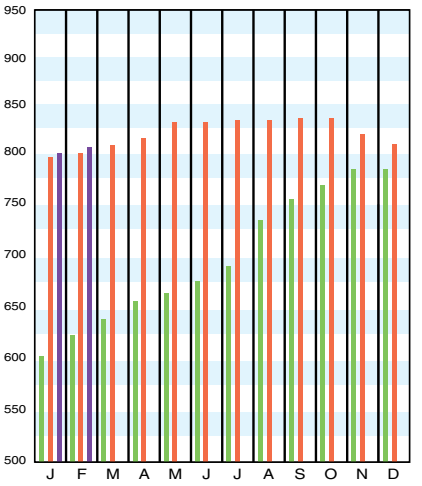
Download the CEPCI two weeks sooner at www.chemengonline.com/pci

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	Feb. '23 Prelim.	Jan. '23 Final	Feb. '22 Final
CE Index	800.6	802.6	801.3
Equipment	1,011.8	1,015.8	1,015.3
Heat exchangers & tanks	829.9	833.1	859.0
Process machinery	1,031.4	1,030.4	1,007.8
Pipe, valves & fittings	1,404.2	1,428.2	1,470.3
Process instruments	565.3	561.7	558.1
Pumps & compressors	1,392.0	1,389.3	1,226.9
Electrical equipment	797.3	795.1	726.9
Structural supports & misc.	1,117.4	1,113.7	1,118.8
Construction labor	359.5	357.8	345.5
Buildings	801.6	795.2	826.0
Engineering & supervision	312.4	312.4	310.3

Annual Index:
2015 = 556.8
2016 = 541.7
2017 = 567.5
2018 = 603.1
2019 = 607.5
2020 = 596.2
2021 = 708.8
2022 = 816.0

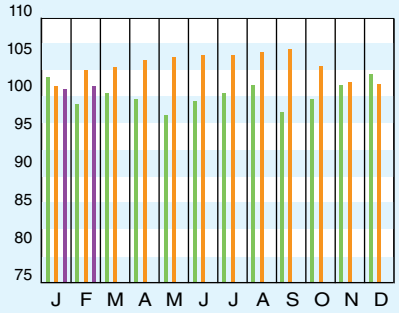
Starting in April 2007, several data series for labor and compressors were converted to accommodate series IDs discontinued by the U.S. Bureau of Labor Statistics (BLS). Starting in March 2018, the data series for chemical industry special machinery was replaced because the series was discontinued by BLS (see *Chem. Eng.*, April 2018, p. 76–77.)



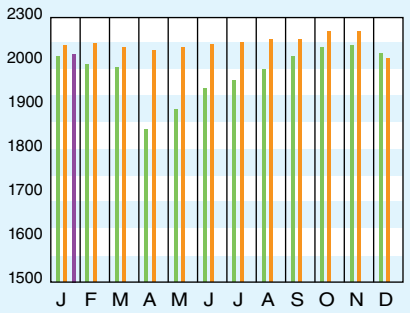
CURRENT BUSINESS INDICATORS

	LATEST		PREVIOUS		YEAR AGO	
CPI output index (2017 = 100)	Feb. '23 =	99.1	Jan. '23 =	99.0	Dec. '22 =	97.1	Feb. '22 =	101.0
CPI value of output, $ billions	Jan. '23 =	2,109.5	Dec. '22 =	2,064.5	Nov. '22 =	2,121.1	Jan. '22 =	1,971.9
CPI operating rate, %	Feb. '23 =	79.6	Jan. '23 =	79.6	Dec. '22 =	78.2	Feb. '22 =	82.0
Producer prices, industrial chemicals (1982 = 100)	Feb. '23 =	325.4	Jan. '23 =	332.8	Dec. '22 =	333.7	Feb. '22 =	341.8
Industrial Production in Manufacturing (2017 =100)*	Feb. '23 =	100.2	Jan. '23 =	100.1	Dec. '22 =	98.8	Feb. '22 =	101.2
Hourly earnings index, chemical & allied products (1992 = 100)	Jan. '23 =	211.6	Dec. '22 =	208.8	Nov. '22 =	209.5	Jan. '22 =	196.6
Productivity index, chemicals & allied products (1992 = 100)	Feb. '23 =	91.6	Jan. '23 =	90.7	Dec. '22 =	88.4	Feb. '22 =	94.6

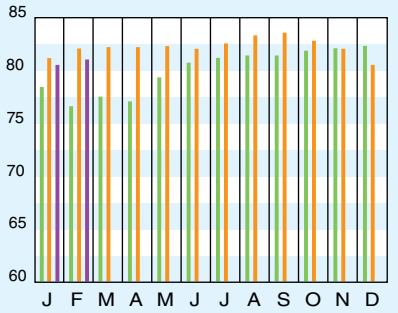
CPI OUTPUT INDEX (2017 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2012 to 2017
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the *CE* Plant Cost Index (CEPCI; top) for February 2023 (most recent available) fell compared to the previous month's value, continuing a series of eight consecutive monthly decreases in the CEPCI overall value. However, the final value for January 2023 was upwardly revised. For February 2023, there was a decrease observed in the Equipment subindex, which offset small increases in the Construction Labor and Buildings subindices. The Engineering & Supervision subindex remained the same. The current CEPCI value now sits at 0.09% lower than the corresponding value from February 2022. Meanwhile, the Current Business Indicators (middle) saw the CPI Output Index edge slightly higher.